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Division of Mechanical Engineering
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Fuels and Lubricants Laboratory
Laboratoire des combustibles et des lubrifiants

NRC B-2400 Single Cylinder Research Engine Test Facility: Dynamometer System Upgrade

B.W. Moyes, H. Rook, M. O'Brien and G.D. Webster

Laboratory Memorandum
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NRC B-2400 SINGLE CYLINDER RESEARCH ENGINE TEST FACILITY: DYNAMOMETER SYSTEM UPGRADE

CONSEIL NATIONAL DE RECHERCHES CANADA, ÉTABLISSEMENT D'ESSAIS ET DE RECHERCHES D'UN MOTEUR MONOCYLINDRE B2400: RENOUVELLEMENT DU SYSTÈME DE DYNAMOMÈTRE.

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Division of Mechanical Engineering
Laboratory Memorandum

Division de génie mécanique
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1990/03

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16. Abstract

This report documents the dynamometer upgrade to the National Research Council's B-2400 single-cylinder, medium-speed diesel research engine. Initial commissioning experiments revealed a coupling problem between the engine and a dynamometer that was too large for this application. The problem was attributed to over-stressing caused by high inertial loading at low cranking speeds from the oversized dynamometer. It was decided to replace the dynamometer with a smaller unit incorporating in-line motoring capability. The report describes the system requirements, acquisition program objective, equipment selection rationale, equipment installation/commissioning and evaluation tests/results. Initial shakedown tests with the new dynamometer system supplied by Midwest Dynamometer Engineering Company met all operational criteria and the engine/dynamometer coupling operation has proven to be satisfactory.

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16. Résumé

Ce rapport décrit les travaux destinés à améliorer la partie dynamomètre-frein du banc d'essai du moteur expérimental monocylindre semi-rapide B-2400, appartenant au Conseil national de recherches. Les essais préliminaires avaient permis de constater que l'accouplement reliant ce moteur au dynamomètre-frein cédait souvent parce que le dynamomètre était trop gros par rapport au moteur. Le problème était dû aux surcharges causées par les forces inertielles élevées du dynamomètre-frein aux vitesses de rotation faibles. Il fut décidé de remplacer celui-ci par un autre moins puissant, avec dispositif d'entraînement intégré. Dans ce rapport, sont décrits le dynamomètre-frein, les objectifs du programme d'acquisition, les critères de sélection, la pose et la mise en service du dynamomètre-frein ainsi que les essais effectués et les résultats obtenus. Les essais préliminaires sur l'ensemble intégré fourni par la firme Midwest Dynamometer Engineering Company ont montré qu'il a atteint les performances escomptées et que l'accouplement se comportait d'une manière satisfaisante.

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SUMMARY

A Bombardier B-2400 single cylinder research engine (SCRE) was acquired by the National Research Council (NRC) in 1986 for fuels, lubricants and component research purposes. Bombardier's design and development of these engines was in part sponsored by Transport Canada (Transportation Development Centre) as a component of their Rail transportation program.

Initial installation of the hardware at NRC's Fuels and Lubricants Laboratory, commenced in the winter of 1985-1986 with commissioning following in January 1987. During the initial tests, persistent failures were experienced on the coupling between the dynamometer and the engine. The failures were attributed to over-stressing caused by high inertial loading of the dynamometer at low crank speeds during and shortly after engine start-up. The dynamometer was essentially too large for this engine application. Since it was the only available dynamometer at the time of installation, it was used for cost expediency.

This report documents the details of the dynamometer upgrade to the SCRE project; the objectives of the upgrade are as listed below:

(i) To determine the feasibility of a smaller (lower inertia) dynamometer replacement to resolve the coupling problem.

(ii) Develop the system requirements and draft a proposal for the allocation of funds.

(iii) Design, acquire, install, calibrate and test the final system.

The new dynamometer system requirements were defined and performance criteria were established. It was determined that the following equipment was required:

(i) Dynamometer

(ii) Dynamometer drive system

(iii) Engine to dynamometer coupling

(iv) Motoring Torquemeter

(v) Load cell

(vi) Compatible mounting frame/baseplate

(vii) Dynamometer controller and torquemeter readouts

Selection of the most appropriate equipment from a number of proposals was carried out on the basis of technical merit, interchangeability with existing laboratory equipment, cost, reliability, past performance record, and component delivery date.

An integral motor/dynamometer system package was preferred to facilitate installation and alignment to the existing B-2400 engine test bed. A list of performance specifications and preferred products was drafted. A number of potential dynamometer system suppliers were invited to submit their proposals.

Information subsequently received from the selected companies led to the acceptance of the Midwest Dynamometer Engineering Company proposal based on its component suitability, cost and the ability to deliver a complete integral system before the end of the 1987-1988 fiscal year.

The final system was inspected and formally received at the Midwest Company plant location (Illinois, USA) before March 31, 1988 and was cleared for shipment by road transport during the first week of April 1988. The system was received and temporarily stored at NRC until final modifications to the existing B-2400 test bed were carried out. The system was installed, aligned and secured on the B-2400 test bed frame by April 22, 1988.

Final calibrations and checkout of the system proceeded throughout August and September, 1988; all minor problems were overcome. Preliminary results indicated that the motoring dynamometer system met or exceeded expectations in areas of its ability to start /accelerate the engine to maximum operational speed, motoring /load absorption speed control stability and coupling durability.

SOMMAIRE

En 1986, le Conseil national de recherches (CNR) s'est porté acquéreur d'un moteur expérimental monocylindre de marque Bombardier B-2400 dans le but d'entreprendre des recherches sur les carburants, les lubrifiants et certains organes. La conception, la réalisation et le développement de ce type de moteur par Bombardier avaient été en partie financés par le Centre de développement des transports, Transports Canada, dans le cadre de son programme de R&D sur le transport ferroviaire.

La mise en place du moteur dans le Laboratoire combustibles et carburants du CNR a commencé à l'hiver de 1985-1986, et la mise en service en janvier 1987. Durant les essais préliminaires, on a noté de nombreuses défaillances au niveau de l'accouplement reliant le moteur au dynamomètre-frein, attribuables aux surcharges causées par les forces inertielles élevées de ce dernier aux vitesses de rotation faibles au moment du démarrage et peu aprés. Le dynamomètre-frein se révélait trop gros par rapport au moteur auquel il était relié. Mais comme c'était le seul disponible, à l'époque, on a continué à s'en servir parce qu'on ne pouvait faire autrement.

Ce rapport explique les travaux visant à améliorer la partie dynamomètre-frein du banc d'essai du moteur expérimental ci-dessus et dont les objectifs étaient de:

i) déterminer la possibilité d'utiliser un plus petit dynamomètre-frein de moindre forces inertielles puissance pour résoudre le problème de l'accouplement;

(ii) définir les caractéristiques du banc d'essais amélioré et établir une proposition visant à obtenir les fonds nécessaires;

(iii) étudier le banc d'essais envisagé et l'installer, l'étalonner et l'essayer après avoir acquis le nouveau dynamomètre-frein exigé.

Les besoins ont été définis et des critères d'évaluation des performances élaborés. Le banc d'essai ainsi défini devait se composer des organes suivants:

(i) un dynamomètre-frein,

(ii) un dispositif d'entraînement,

(iii) un accouplement moteur-dynamomètre,

(iv) un couple-mètre,

(v) un capteur de forces,

(vi) une base et un bâti compatibles,

(vii) un régulateur de la puissance absorbeé et un dispositif d'édition des valeurs de couple.

La sélection des organes les plus appropriés, à partir des propositions reçues, a été faite en fonction de plusieurs facteurs: qualité technique, interchangeabilité avec le matériel de laboratoire existant, coût, antécédents et rapidité de livraison.

La préférence est allée à un ensemble moteur-dynamomètre intégré, pour la raison qu'il rend plus facile l'installation et l'ajustement sur le banc d'essai existant. Une spécification a été élaborée et la liste des organes à privilégier dressée. Des demandes de proposition ont été adressées à un certain nombre de fournisseurs choisis.

C'est finalement la proposition soumise par Midwest qui a été sélectionnée pour les raisons suivantes: appropriation des organes proposés, coût et livraison d'un ensemble complet avant la fin de l'année financière 1987-1988.

L'ensemble a été officiellement réceptionné à l'usine de Midwest, avant le 31 mars 1988, et a reçu les documents nécessaires à son transport par route et à son dédouanement, au cours de la première semaine d'avril 1988. Le CNR, ayant pris livraison de cet ensemble, l'a gardé en magasin en attendant que soient achevées les modifications nécessaires au banc d'essai. L'ensemble a été installé, ajusté et boulonné au banc d'essai et se trouvait fin prêt le 22 avril 1988.

Les derniers travaux d'étalonnage et de vérification ont eu lieu en août et septembre 1988, de manière à parfaire l'installation. Les essais préliminaires ont montrés que cet ensemble intégré atteint ou dépasse les performances escomptées: aptitude à lancer le moteur expérimental et à lui faire atteindre rapidement sa vitesse de rotation maximale; régulation de la puissance absorbée ou produite et maintien de la vitesse de rotation, et durabilité de l'accouplement.

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NRC B-2400 SINGLE CYLINDER RESEARCH ENGINE TEST FACILITY: DYNAMOMETER SYSTEM UPGRADE

1.0 INTRODUCTION

In 1986 the National Research Council (NRC) acquired for fuels, lubricant and component research purposes a Bombardier single cylinder research engine (SCRE). This engine was designed and built by Bombardier specifically for research and development purposes. The design and development of these engines was sponsored by Transport Canada's Transport Development Centre (TDC) as part of their Rail Transportation R&D Program. The NRC SCRE was Bombardier's new medium-speed diesel engine design, the B-2400. This engine design incorporates advanced technology that permits theoretical output power levels to 400 brake horsepower per cylinder at a maximum speed of 1200 rpm.

During the winter months of 1985-86 the NRC test cell was constructed, the engine-dynamometer was installed in May, 1986 and the first engine start-up occurred three months later. Computer based system controllers/data acquisition and instrumentation were installed and calibrated during the remainder of 1986. Initial shakedown tests commenced during January, 1987. During these tests and subsequent calibration experiments, the coupling between the dynamometer and the engine experienced a number of failures. In addition, the air start system required frequent rebuilding. The coupling problem was attributed to over-stressing due to high inertial loading from the dynamometer at low cranking speeds during/after engine start-up. The dynamometer employed in this system was oversized (1000 hp absorption capability) for the SCRE application. Installation of a more capable coupling would have necessitated a costly movement of the dynamometer on the test bed. It was believed that the existing coupling would have fared better if higher cranking speeds during engine start-up were possible. Unfortunately, the air start system employed lacked this capability due to the large dynamometer inertial/frictional resistance loading. Air start systems of a larger capacity would have required modifications to the engine and air supply hardware. Future requirements to motor the engine for component screening experiments led to consideration of the concept of a dynamometer replacement with a smaller unit incorporating in-line motoring capability. TDC having recognized the problems associated with the existing dynamometer, agreed to sponsor a project to upgrade the installation in their interest to promote and support the availability of appropriate test facilities for the conduct of rail R&D programs.

2.0 ACQUISITION PROGRAM OBJECTIVES

The first objective of the proposed concept, in light of physical/cost constraints, was to determine the feasibility of a smaller dynamometer with in-line motoring capability. If positive feasibility resulted, the second objective would be to develop the system requirements and a subsequent proposal for allocation of funding. If funding was available, the final objective would be to design, acquire, install, calibrate and test the new system. This report documents the fulfillment of these three objectives.

3.0 SYSTEM REQUIREMENTS

The initial step in a dynamometer replacement project of this nature is to establish the system requirements. The new equipment must satisfactorily accomplish/improve functional duties of the old equipment while enabling fulfillment of the desired new objectives. In addition, some of the existing equipment must be altered and upgraded in order to accommodate the new equipment.

With these considerations, along with the rationale for the dynamometer upgrade, the following set of requirements were defined:

1. The dynamometer must be capable of absorbing a minimum torque of 2030 N•m (1500 lb-ft) throughout the B-2400 engine operational speed range (400 → 1100 rpm) and an overall maximum power absorption rating of 400 brake horsepower.

2. The new set-up must be capable of motoring the engine with the engine intake air at maximum boost pressure (4 bar), the dynamometer at maximum coolant flow (180 L/min), and accurately control motoring speed (± 5 rpm) throughout the operational speed range of the engine (400 → 1100 rpm).

3. The motoring system must be capable of unassisted cranking of the engine (i.e., overcome all system inertia/friction from the engine and dynamometer) for starting purposes.

4. Engine to dynamometer coupling method must be able to withstand momentary peak torques of at least 10,000 N•m (a minimum factor of safety of four times the nominal maximum engine torque is desireable).

5. An in-line, direct coupled torque cell (minimum 1000 N•m capacity) was required to provide an analog output of system motoring torque for measurement purposes.

6. A method of de-clutching the electric motor drive system from the dynamometer be provided.

7. Electrical power must be provided to the test cell for motoring operations and tailored to the new equipment (i.e., compatible voltage and current).

8. Electrical upgrade of existing building power system was required to accommodate electric motor power absorption requirements.

9. Modification of existing test bed framing was necessary to facilitate mounting and alignment of new equipment.

These are the primary technical requirements of the system. There was also a time restriction placed on the project. This was a result of budgetary considerations, as it was necessary to receive delivery of the equipment by March 31, 1988.

In summary, the following is a list of the required system components:

- Dynamometer
- Dynamometer drive system (including motor, power supply, and speed controller)
- Engine to dynamometer coupling (including adapter plate if necessary)
- Torquemeter
- Load cell
- Mounting frame/baseplate compatible with existing framing
- Any necessary hardware to couple components and attach assembly to baseplate
- Dynamometer controller readout and torquemeter readout
- Laboratory electrical distribution transformers

4.0 EQUIPMENT SELECTION

The next step in this project was the selection of the most appropriate equipment for the facility. The system components were selected on the basis of several criteria. From a technical viewpoint, they had to meet the requirements previously set down (refer to Section 3.0). In addition to these criteria, the components were chosen on the basis of cost, reliability, past performance record, availability (because of delivery deadline) and compatibility with existing laboratory equipment.

The first step in the selection process was to contact various sources of information in order to develop a list of components that met the system requirements. These components were then evaluated individually and a specific product was selected to fulfill the need for each part of the system. The list of preferred products was then supplied to several dynamometer companies. These companies were invited to submit proposals to supply the necessary equipment. The proposals were then evaluated and the most feasible/cost effective one was selected for the project.

The following sections detail these selection processes. Sections 4.1-4.7 deal with the individual component evaluations. The final section, Section 4.8, addresses the choice between the submitted proposals from the dynamometer companies.

4.1 Dynamometer Type

Because the actual dynamometer selected would depend on the overall proposal from the supplier, the only specification that was required from NRC was the type of dynamometer to be furnished by the supplier (i.e., eddy-current versus water-brake). The eddy-current type was chosen as the superior type for our application. The water-brake type was deemed unsuitable as it would be unable to meet the stringent load and speed control stability required for this research facility. Water-brakes are generally more suited to industry (production testing) applications. An attractive feature of water-brakes is their low cost relative to the eddy current alternative.

The significantly higher capital cost for an eddy-current dynamometer was overcome by attempting to acquire a factory rebuilt dynamometer rather than a new one. This strategy would be satisfactory if an adequate warranty could be obtained.

4.2 Electric Drive Motor

From NRC's point of view, the selection of the electric motor for the dynamometer drive system involved the choice between an A.C. (alternating current) or a D.C. (direct current) type motor. The choice of motor manufacturer was left up to the supplier, providing the selected motor met with the requirements of the overall system.

It was found that A.C. motors were not appropriate for this application. Torque characteristics vary with design, but A.C. motors generally exhibit low torques at low speeds and the torque output varies throughout the motor's operational range. This was unacceptable, as relatively constant, high torque, is needed at low speeds to overcome the engine and dynamometer friction/inertia for starting purposes.

As a result of the low starting torque, a significantly higher power rated A.C. motor would be needed to provide the required torque for cranking. This solution is feasible but would be a needless waste of space, weight, cost and electrical power consumption. In addition, the speed accuracy required for our purposes was not viable with an A.C. adjustable frequency drive unit.

In contrast, D.C. electric motors provide close to full torque throughout their complete speed range. Torque output remains relatively constant for 95% of the motor's speed range (from 5% to 100%), with approximately 85% of peak torque output available at 1 rpm. It was thus decided that a D.C. motor was superior for this application on the basis of starting torque and overall torque output characteristics.

4.3 Engine To Dynamometer Coupling

The coupling selected for this application was the Holset Model CB-5 [Fig. 1]. This unit was selected over other candidates due to several unique design features that made the Holset coupling the most attractive for this project.

The primary feature that made this coupling desirable was its fail-safe design. The coupling incorporates compressed solid rubber cylindrical blocks between the blades of an outer hub and an inner sleeve. This arrangement ensures that the coupling will continue to transmit torque, even if the rubber blocks fail prematurely. Thus, the engine could still be controlled (ie., shutdown) in the event of a coupling failure.

In addition, the damping properties and torsional stiffness of the coupling may be custom tailored to an application by changing the rubber blocks. These elements are available in varying durometer hardness to facilitate this modification. This design feature allows the coupling to be set-up so that

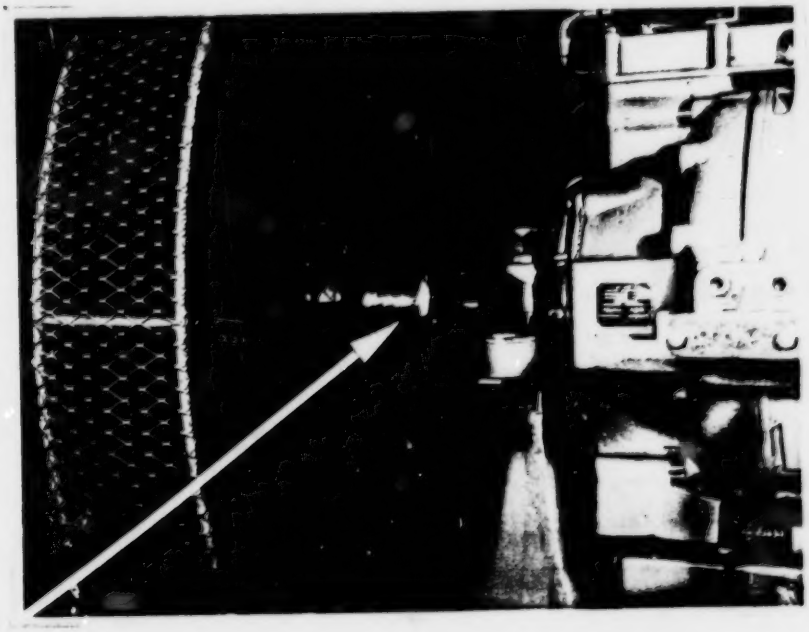

Figure 1. Holset CB-5 Coupling

operation through the natural frequency of the equipment has a minimal vibratory effect on the system.

Besides these features, the Holset design was also able to meet the specified system requirements. The coupling was required to withstand the continuous and peak torque ratings as well as having adequate vibratory torque damping characteristics. The Holset CB-5 sufficiently met these specifications and actually exceeded the indicated factor of safety of four, increasing it to six. This factor is adequate for all foreseeable future experimental work which may involve excessive rates of combustion pressure rise and/or poor engine starting characteristics.

Finally, the enclosed design of the coupling provides an added bonus in that it employs limited environmental protection to the rubber elements which could be damaged by exposure to the harsh environment provided by the diesel fuel and lubricating oil.

4.4 Load Cell

There were several criteria considered in the selection of a load cell for this application. It was desirable to obtain a load cell with a rugged, proven design. Ideally, it would be designed for a dynamometer application similar to this one.

Because of the extraneous vibratory loads produced by the single cylinder test rig, a load cell with low sensitivity to such loads would be required.

The load cell should be adequately oversized to ensure that the cell can withstand peak loads. However, it is important to keep the range sufficiently small so that accuracy is maintained within the operational range of the engine.

A Lebow 3169 load cell [Fig. 2] was selected as it satisfied all of the above criteria. In addition, this load cell is compatible with existing laboratory equipment. An identical model, previously installed on the existing test rig, can be accessed quickly for emergency replacements with a minimum of system down-time.

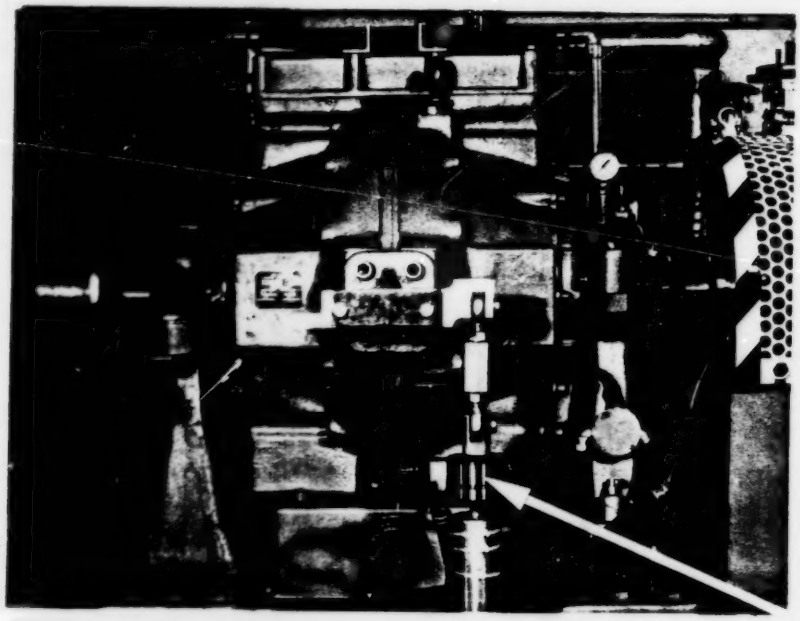

Figure 2. Lebow 3169 Load Cell (in foreground)

4.5 In-Line Torquemeter

One of the major constraints placed on the selection of the torquemeter was size. Because it was desirable to have an in-line torquemeter set-up within the very limited length available on the existing B-2400 test bed, there was only a narrow range of dimensions permissable for the torquemeter. The in-line set-up was highly desirable because it would facilitate alignment and eliminate the requirement of offset equipment. Such offset equipment with drives through pulleys/belts lead to complexity, unwanted parasitic losses and safety considerations.

In addition, it was required that the torquemeter was of high capacity, flanged for easy removal, compact, and able to provide continuous monitoring. A peak torque capacity of at least twice the D.C. motor torque was requested.

The Himmelstein MCRT 6-02T non-contact torquemeter [Fig. 3] met all dimensional and application requirements. Also, the Himmelstein model readout, with the appropriate modules, provided the necessary monitoring functions to meet the NRC requirements. Himmelstein equipment has, in the past, proven to be reliable in similar applications.

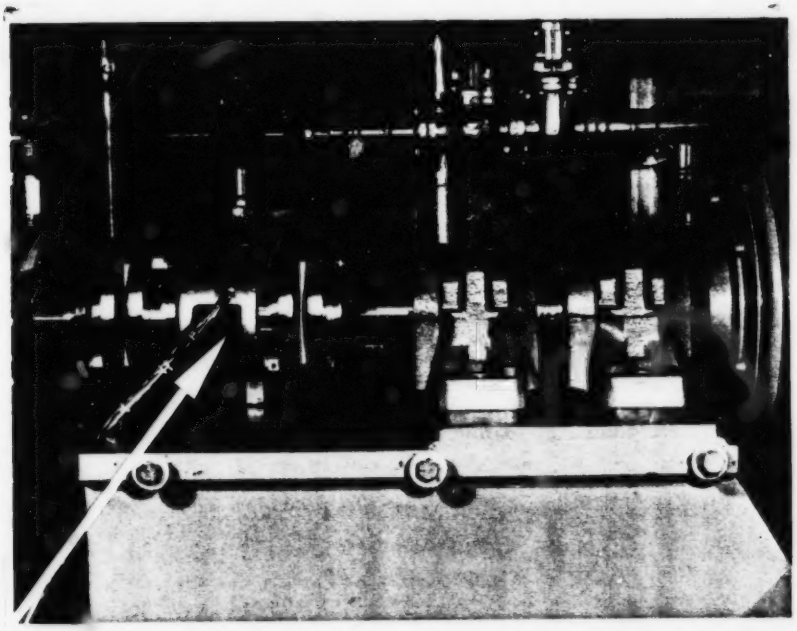

Figure 3. Himmelstein MCRT 6-02T Torquemeter

4.6 Electric Clutch

The requirement to completely disconnect the D.C. electric motor from the engine/dynamometer during normal engine testing necessitated the use of a clutch system. A Warner Electric Clutch model HT 1525 [Fig. 4] was selected to perform this function.

The Warner clutch selected is an electromagnetic device with two basic parts: a magnet faced with a friction pad material and an armature (friction disc). When D.C. voltage is applied to the coil, the armature and the magnet are attracted together, transmitting torque proportional to the voltage applied. This allows positive, instantaneous engagements or soft cushioned starts.

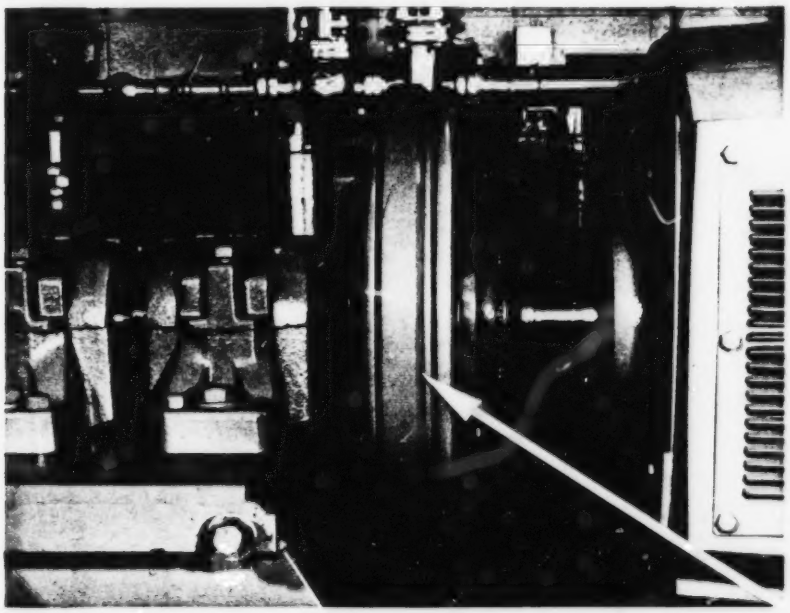

Figure 4. Warner Electric Clutch

The clutch design permits a complete uncoupling between the electric motor shaft and the dynamometer shaft. This ensures that there are no parasitic frictional losses in the clutch at high differential input/output speeds, as is the case with other clutch drive systems (e.g., over-running sprague type designs).

The clutch operation presently requires only on/off operation, easily controlled by a remote control room mounted toggle switch. Future requirements for proportional torque control can be easily accommodated by installation of an inexpensive proportional voltage controller.

The torque capacity of the selected model is approximately three times the maximum D.C. motor torque to ensure durability and slip-free operation under high cyclic torsional variations. Simplicity in design and maintainability should provide a long life and reliable operation.

4.7 Dynamometer Controller

The Digalog Dynamometer and Throttle controller (slave unit) are the heart of the presently installed engine control system. These units [Fig. 5] provide the necessary interface to provide manual control via panel mounted ten turn potentiometers and digital meter readouts. In addition, they allow for external (remote) setpoint control and monitoring for all engine operating and measured parameters via the laboratory, Leeds and Northrup Max I multi-loop process control system, Fluke 2240 B Datalogger and DEC PDP 11/24. Engine speed, load, torque, power and fuel injector rack position are monitored and controlled through these units.

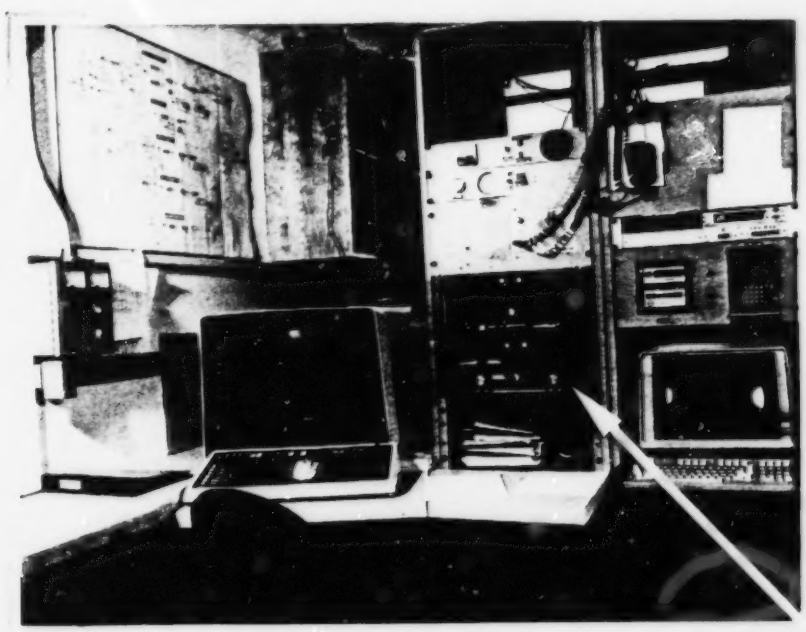

Figure 5. B-2400 Control Room showing Digalog Controller

This controller was selected in 1986 on the basis of previous experience by NRC and others. The system has provided relatively reliable, accurate service in applications of this nature. An additional, identical Digalog Dynamometer controller is also available to provide immediate backup capability in the event of an equipment failure.

4.8 Proposal Selection

After a literature survey, the system components were selected (refer to previous sections). This list was then furnished to various companies who could supply the needed equipment as an integrated package. An integrated unit was preferred as it would allow easier installation and alignment to the B-2400 engine. As a result, the following firms[1] were approached during the first week of December (1987):

1. Midwest Dynamometer and Engineering Company.
2. Relcon Incorporated (representatives of Eaton Corp.)
3. Schenck Pegasus Corporation.

From the information sent by these suppliers, it was decided that the "Midwest" offer was the only feasible route to follow. Their proposal (see Appendix A) surpassed the other candidates initial proposals in the areas of component suitability, cost and delivery as specified by the Fuels and Lubricants Laboratory personnel. Specific details are as follows:

1. The ability of Midwest Engineering to provide a factory rebuilt dynamometer with full warranty, within the specified time constraints, for the purpose of minimizing costs.

2. Compatibility and Interchangeability of Equipment and Instruments. The Fuels and Lubricants Laboratory presently has a duplicate Midwest Model 1519-W dynamometer and Digalog dynamometer controller installed on another test rig. This would enable an emergency substitution of the dynamometer or the control system in the event of an equipment failure, with a minimum of test facility downtime.

3. Performance Proven Capabilities. The similar existing dynamometer and Digalog control system provide accurate control and reliable operation as proven by extensive operation on other Fuels and Lubricants Laboratory test rigs.

[1] Note: There are no Canadian manufacturers of this specialized engine testing equipment.

4. The D.C. variable speed electric drive motor and controller provide a constant maximum torque and accurate speed control characteristics throughout the entire operational speed range. This characteristic provides superior mechanical and electrical performance over the AC type variable speed motors proposed by the alternative candidates.

5. The engine coupling, clutch, torquemeter and load cell components as selected by NRC would be incorporated into the design of the assembly, enabling an overall motoring dynamometer system warranty to be provided by Midwest Dynamometer Engineering Company.

6. Midwest Engineering would supply a totally engineered bed-plate and instrument mounting configuration [Fig. 6]. This ensures precision alignment of all devices and enable bolt-on mounting to the existing framework of the B-2400 engine within the specified space constraints.

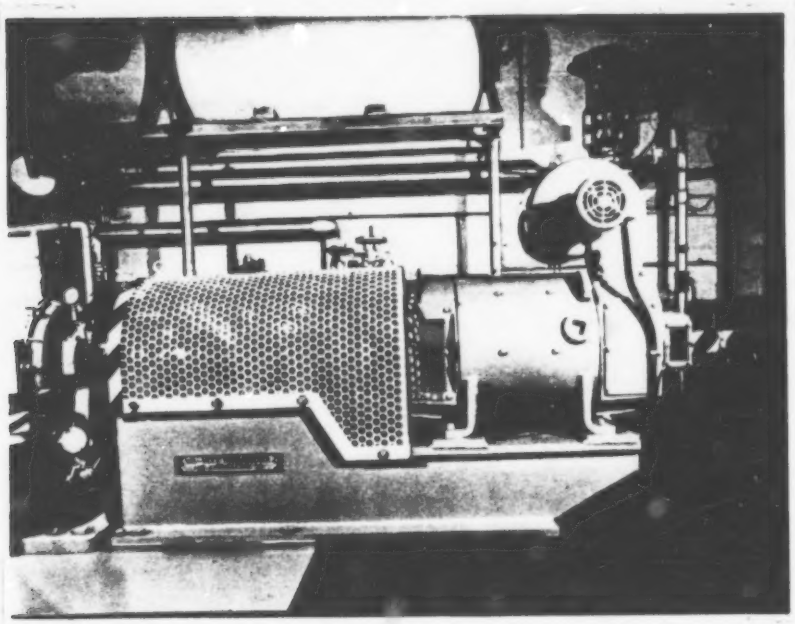

Figure 6. Overall Unit Installed On Test-Bed

5.0 EQUIPMENT INSTALLATION AND COMMISSIONING

The prime contractor for the D.C. motor/dynamometer assembly was Midwest Dynamometer and Engineering Company, Illinois, U.S.A. Formal NRC inspection and acceptance was taken on March 31, 1988 at the Midwest plant in Chicago, Illinois.

The system was shipped by road transport the first week of April, and arrived at NRC secure and undamaged. To prepare and effect the installation, specialized heavy equipment movers were contracted to remove the existing dynamometer from the test bed. This necessitated the removal of the B-2400 engine from the framework. At this time, redesign and modification of the existing B-2400 frame-rails were carried out, including reinforcing of existing I-beams and installation of mounting pads for the new assembly. The motor/dynamometer assembly and the B-2400 engine were successfully installed and secured on the test bed by April 21, 1988 [Fig. 7 and Fig. 8]. A specialized NRC millwright was utilized to ensure correct alignment of the dynamometer to the engine.

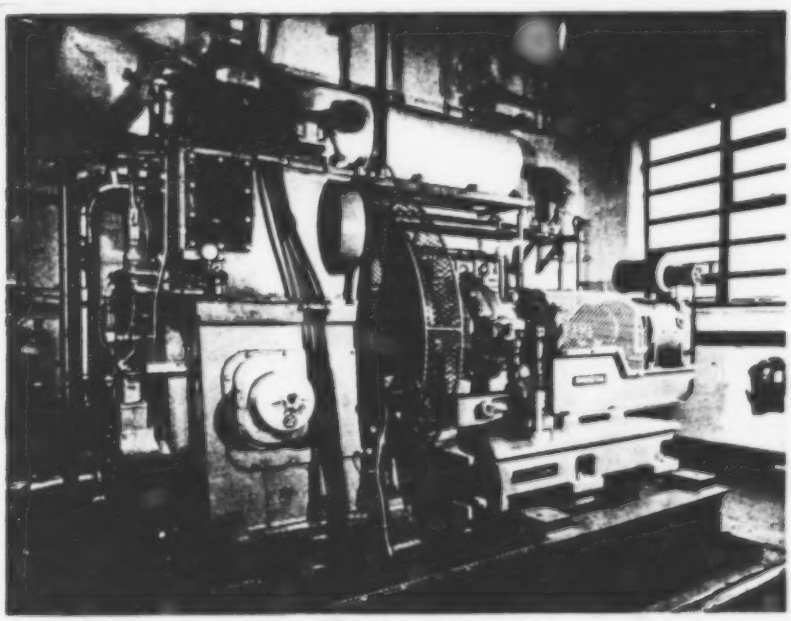

Figure 7. Installed Unit Viewed From Front

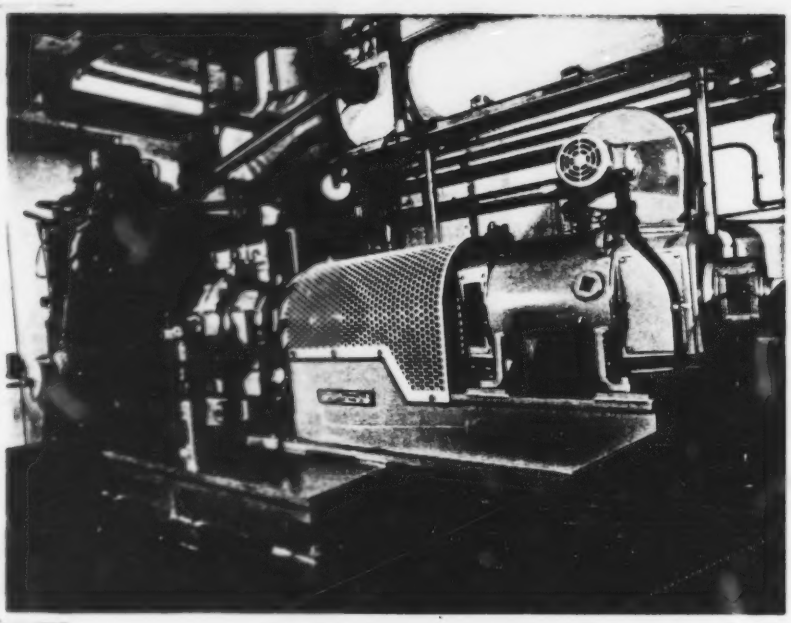

Figure 8. Installed Unit Viewed From Rear

Simultaneous to this operation, installation of the high voltage electrical wiring and procedures to upgrade the laboratory's electrical supply were underway.

All aspects of the electrical work were co-ordinated and carried out under the engineering and contract management supervisor of NRC Plant Engineering Services. Substantial electrical upgrading of other areas of the Montreal Road complex of NRC was underway at the same time. All electrical service requirements of our project were co-ordinated with the NRC site contracted electrical firm using contract amendment procedures.

Two phases of electrical work were undertaken. Phase I requirements included the installation of a high voltage step-down transformer (600 VAC → 460 VAC) to feed the S.C.R. (silicon controlled rectifier) control system of the electrical motor in the M-9 transformer room [Fig. 9]; routing of high capacity distribution cabling to the test cell area; cabling from the S.C.R. cabinet [Fig. 10] to the D.C. motor; and miscellaneous hookup and control wiring.

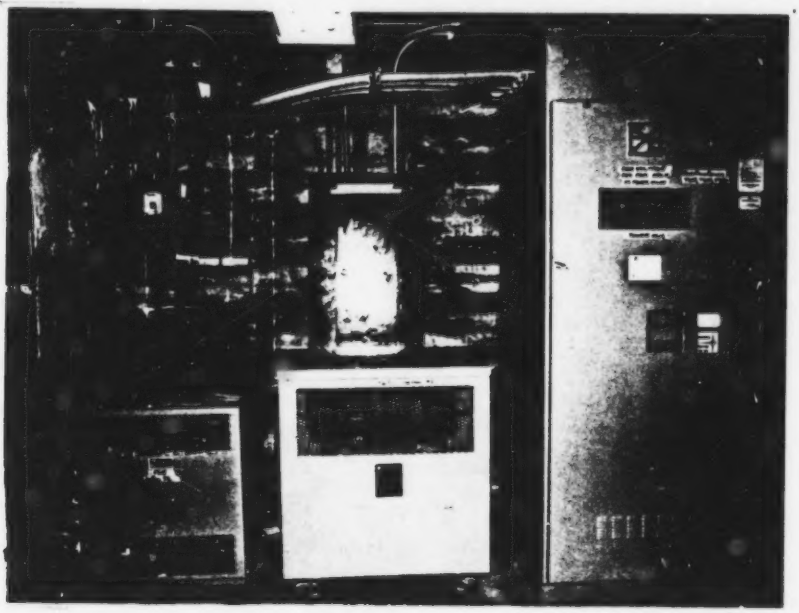

Figure 9. High Voltage Step-Down Transformers

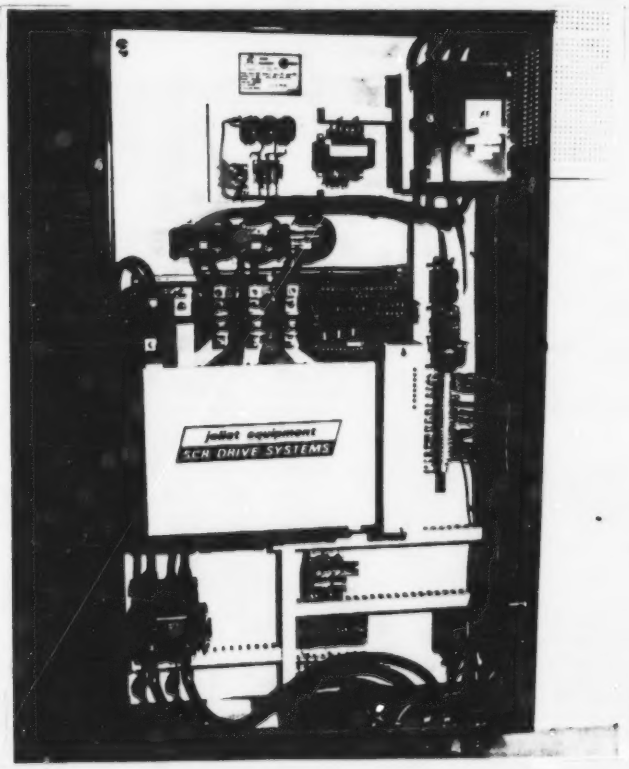

Figure 10. D.C. Motor S.C.R. Controller (internal chassis)

Phase II requirements included the isolation of the laboratory electrical feed from the adjoining laboratory (M-7) electrical service panel; and the upgrading of M-9 electrical service panel from the existing 200 Amp @ 600 VAC to a minimum 480 Amp @ 600 VAC. This work required the removal of existing switch gear/ transformers and acquisition/installation of new feed cabling and upgraded transformers [Fig. 11].

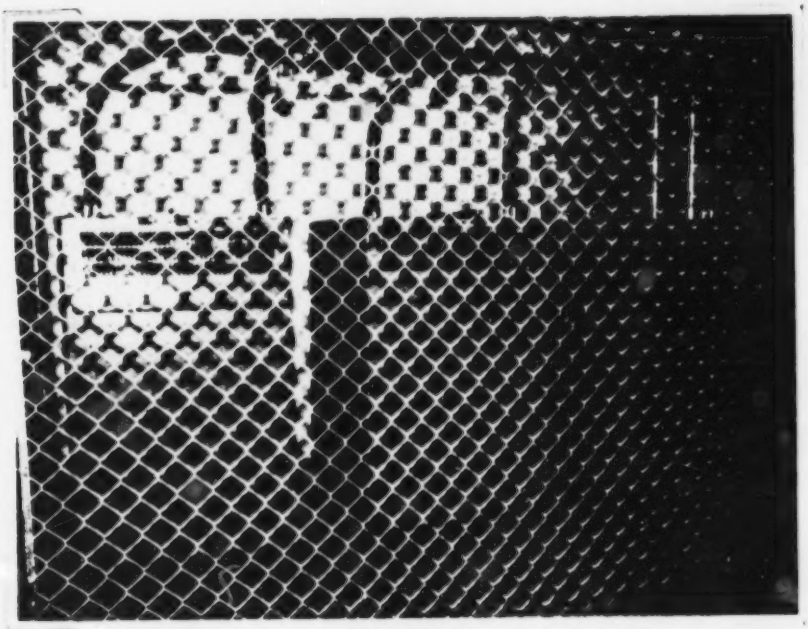

Figure 11. Distribution Transformers

Phase I electrical work was completed promptly and allowed for preliminary, light-duty testing of the D.C. motor/S.C.R control system and dynamometer controller and instrumentation calibration throughout the month of May, 1988. Maximum load motoring tests were not possible due to overall laboratory power supply limitations, as a result of delays incurred in the completion of the Phase II portion of the contract. An electricians strike and delays in delivery of the electrical power feed transformers were experienced throughout May, 1988. However, all aspects of Phases I and II of the electrical upgrade project were successfully completed and commissioned by late June, 1988. Throughout July, 1988 final calibration of the D.C. motor and S.C.R. control system and preliminary B-2400 engine motoring tests were carried out.

The final aspects of system checkout and calibration proceeded throughout August and September, 1988. During this time, other improvements made to the test cell, including cooling tower upgrading, combustion air filtering systems and construction of a cylinder head removal/installation tool, were carried out and commissioned. Some problems with respect to the transducer installation in the B-2400 cylinder head delayed final full load firing and motoring performance checkouts until mid-September, 1988.

Further testing of the engine under a broad range of setpoint conditions is required to optimize dynamometer controller stability. However, all preliminary data indicates that the motoring dynamometer system meets or exceeds expectations in the areas of ability to start/accelerate the engine to maximum operational speed, motoring/load absorption stability and coupling durability.

6.0 EQUIPMENT EVALUATION TESTS

6.1 Start-Up Motoring Performance

6.1.1 Purpose

The purpose of this test was to evaluate the ability of the D.C. Motor to accelerate the overall motor/dynamometer system from rest (0 rpm) to maximum speed (1100 rpm), demonstrating the capability to provide unassisted starting (no air starter used) and to provide for friction and inertia measurements on the engine throughout its speed range.

6.1.2 Initial apparatus settings

1. Engine boost pressure setting: 10 kPa.
2. Dynamometer water pressure: 200 kPa.
3. Engine lubricating oil and jacket cooling water systems "ON" and stabilized at operating pressures and flows.

6.1.3 Procedure

1. Manually crank engine to top-dead-centre (TDC) on the compression stroke.
2. Set D.C. motor speed control to maximum.
3. Record time in seconds, D.C. motor current in D.C.Amps, and D.C. motor torque output in Newton-metres, to accelerate B-2400 engine/dynamometer to maximum speed. Data recorded every 100 rpm up to 1100 rpm.
4. Upon reaching 1100 rpm, return D.C. motor speed control to minimum.
5. Stop B-2400 engine by dynamometer loading from dynamometer controller.
6. Repeat test procedure (Steps 1 to 5) to obtain a second set of data and average readings.

6.2 Fired/Motored Performance Evaluation

6.2.1 Purpose

To observe motored and fired performance at three notch setpoint conditions.

Notch settings 3, 6, and 8 were selected to reflect a wide range of engine speed, power output, boost pressure and temperature setpoints. These setpoints were chosen to adequately evaluate the system performance for:

1. speed control regulation and stability during motored and fired tests,
2. overall dynamometer load absorption capability to the current maximum B-2400 engine power output setpoint,
3. motoring capability of the system with maximum engine speed, boost pressure and dynamometer water drag, and,
4. evaluating test bed/dynamometer vibration phenomena which may occur.

6.2.2 Procedure

The following steps were used:

1. Start and warm-up of engine to stabilize operational conditions using normal procedures.
2. Engine set at Notch 3 fired condition operating parameters using Leeds and Northrup Max I process controller, and stabilize.
3. Acquisition of a cylinder (combustion) pressure trace using DEC PDP 11/24 [Fig. 13, Fig. 14 and Fig. 15].
4. Acquisition of steady state data of all peripheral system operating parameters (average conditions over two minutes of stabilized operation at setpoint) to determine stability deviations, using the Fluke Data-logger and the PDP 11/24 analysis routine.
5. Phase in of D.C. motor speed control to engine speed setpoint.
6. Engagement of eddy-current clutch.
7. Reduction of engine fuel rack position to zero fueling.

8. Acquisition of a cylinder pressure trace (Step 3) [Fig. 13, Fig. 14 and Fig. 15].

9. Acquisition of steady state data over two minute run (Step 4).

10. Recording of D.C. motor current and torque readings.

11. Repetition of Steps 2 through 10 for each setpoint at Notch 6 and Notch 8.

12. Cooling down stopping of engine using normal procedures.

7.0 TEST RESULTS

The following test results in Table 1 and Table 2 document equipment evaluation test procedures described in the previous sections 6.1.3 and 6.2.2. Refer to acceleration curve [Fig. 12] for plot of results.

Table 1. Start-Up Motoring Performance

(D.C. Motor: 165 Hp @ 1750 rpm, 110% continuous rating)

Engine Speed (rpm)	Starting Current (D.C.Amp)	Starting Torque (N•m)	Average Time (sec)
0	0	0	0
100	255	671	5.8
200	255	675	9.5
300	255	667	13.5
400	255	660	17.6
500	255	657	21.8
600	255	654	26.8
700	255	654	32.2
800	255	655	38.0
900	255	658	45.4
1000	255	658	54.0
1100	255	658	65.0

Table 2. Fired/Motored Performance Evaluation

Operating Mode	Engine Speed[1] (rpm)	Engine Boost (kPa)	Dyno Load (N•m)	Engine Power (kW)	Motor Current[2] (D.C.Amp)	Motor Torque[3] (N•m)
Notch 3:						
Fired	600	9.0	471	29.6	-	-
Motored	600	9.0	38[4]	-	280	100
Notch 6:						
Fired	900	76.0	1061	100.1	-	-
Motored	900	76.0	72[4]	-	345	125
Notch 8:						
Fired	1100	203.0	1586	182.7	-	-
Motored	1100	203.0	99[4]	-	376	140

[1] Tolerance: ± 2 rpm
[2] Average value
[3] Tolerance: ± 1 %
[4] Load due solely to dynamometer coolant water drag; (Dynamometer Water Pressure: 200 kPa)

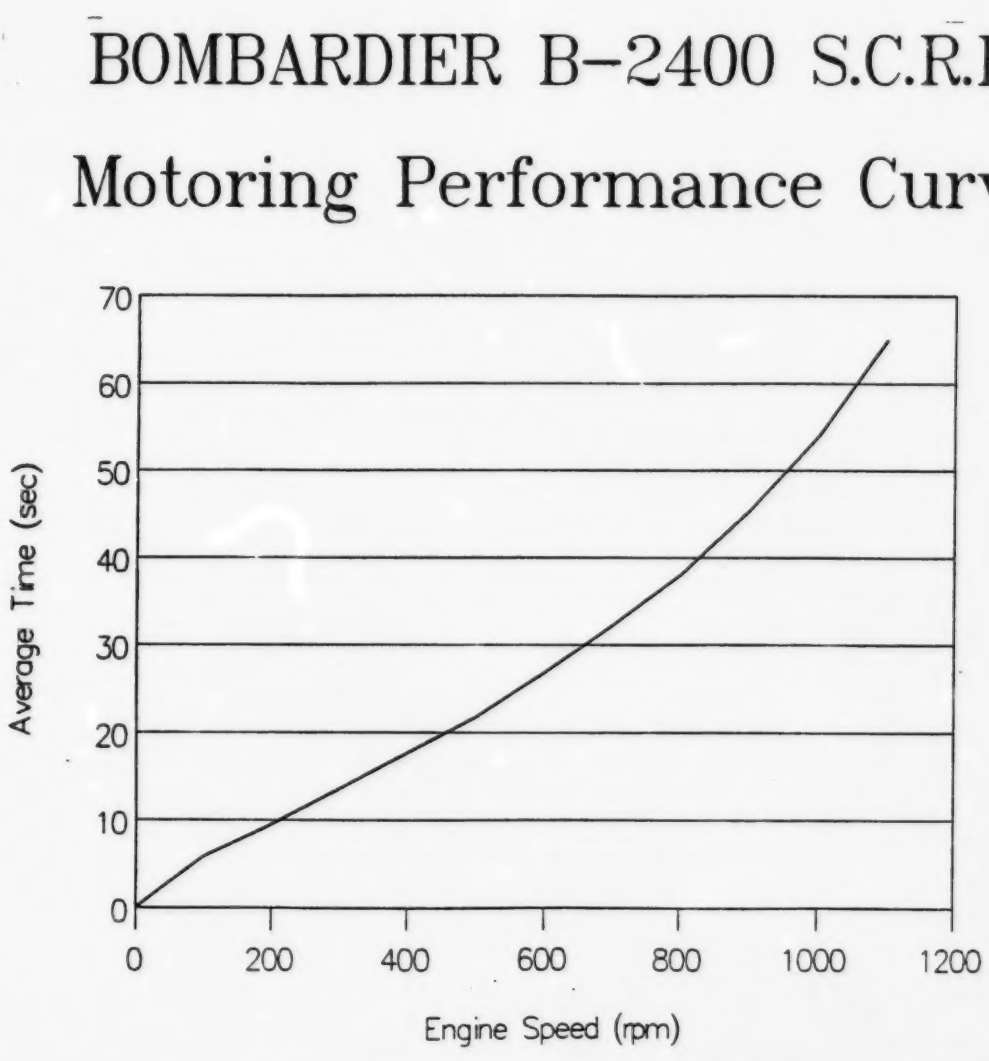

Figure 12. B-2400 Motoring Performance Curve

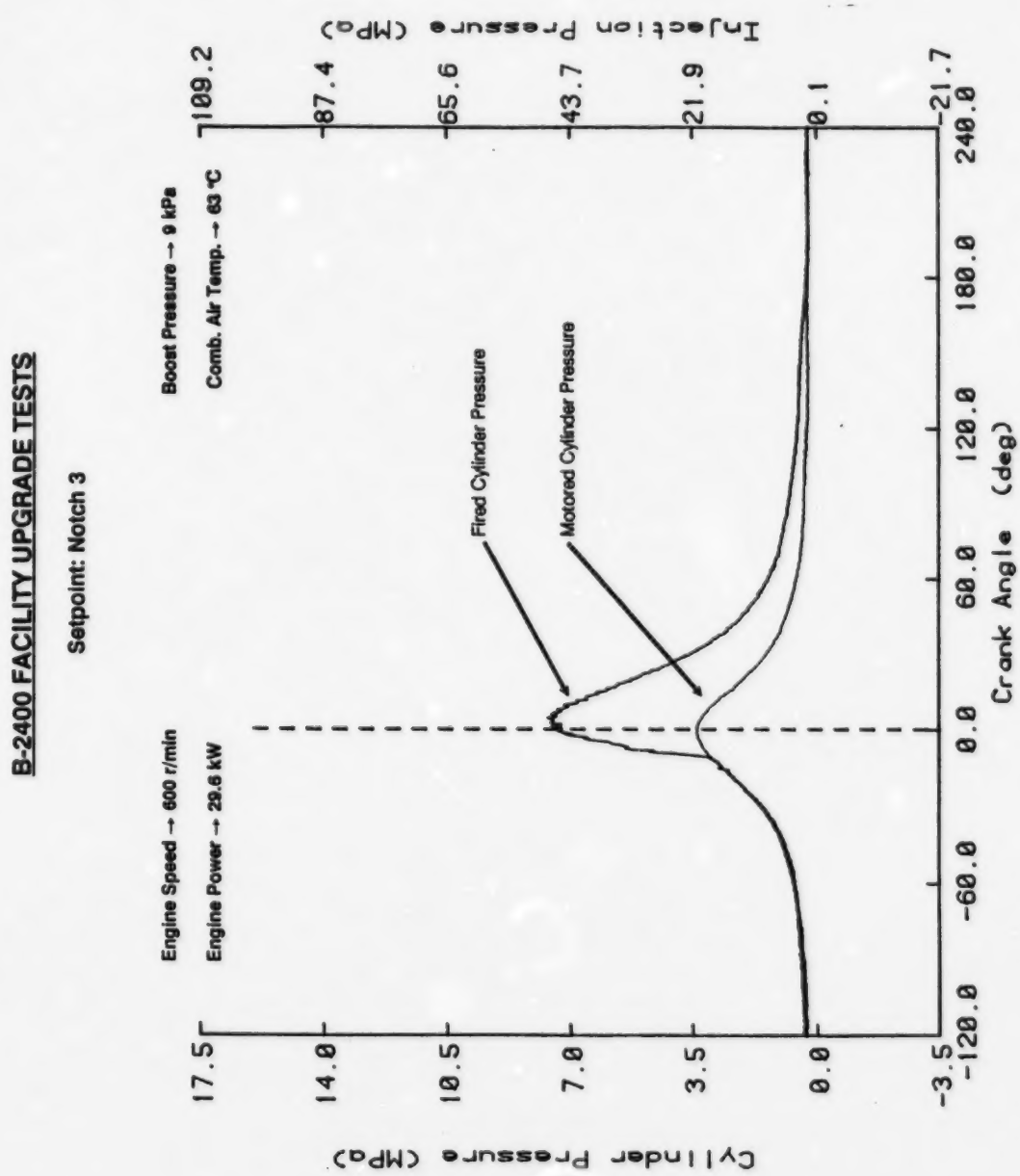

Figure 13. Cylinder Pressure Waveforms - Notch Setpoint 3

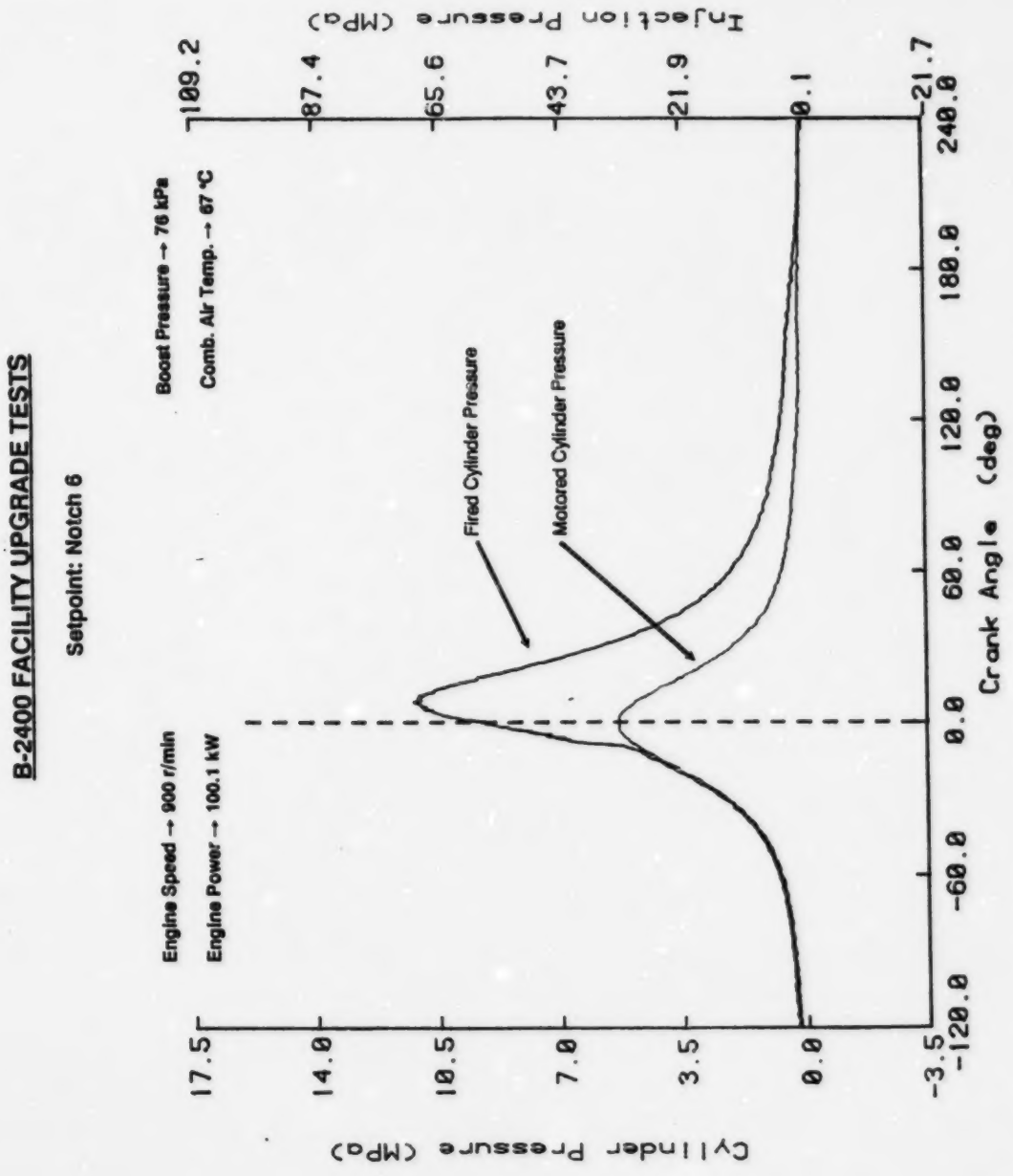

Figure 14. Cylinder Pressure Waveforms - Notch Setpoint 6

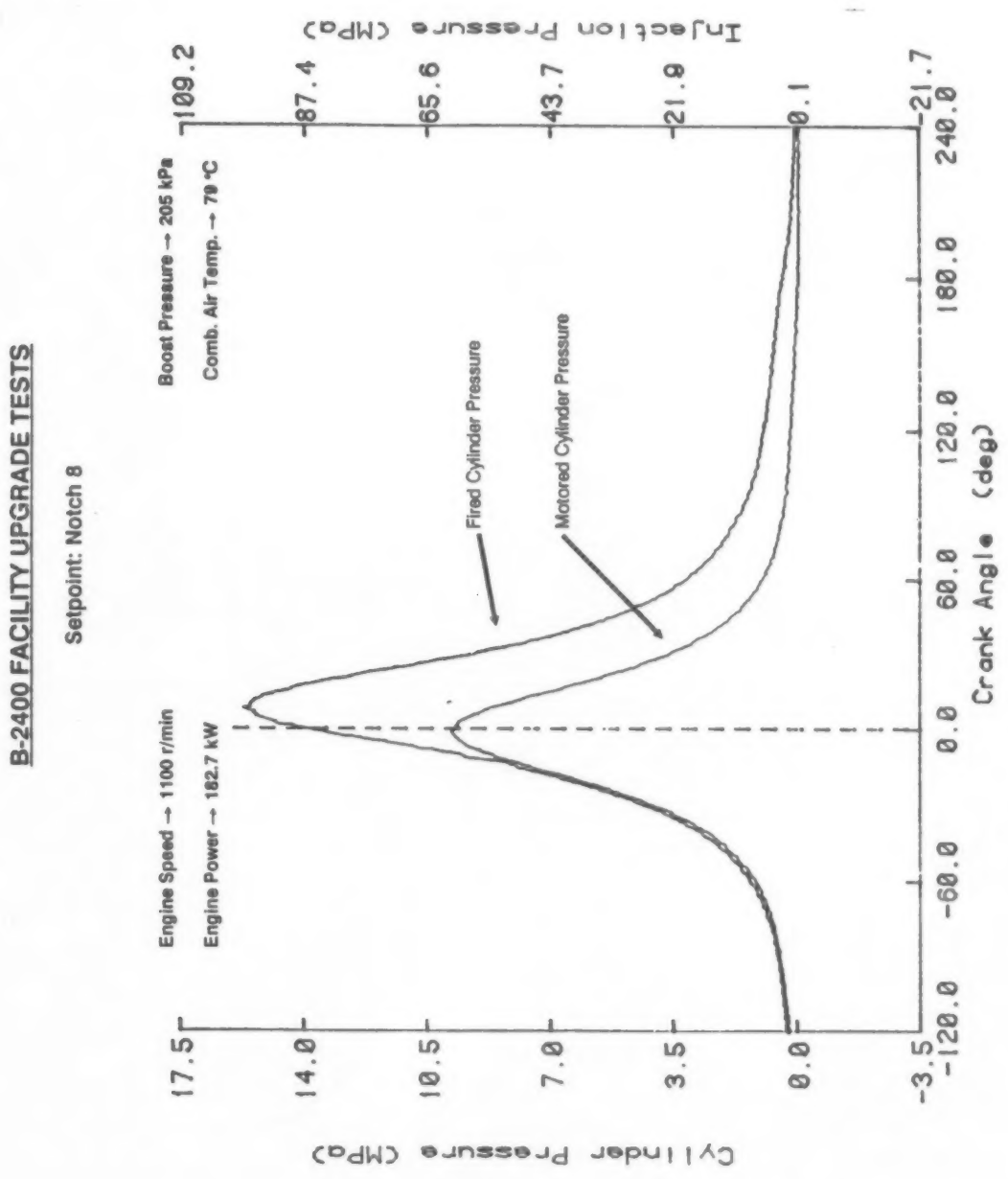

Figure 15. Cylinder Pressure Waveforms - Notch Setpoint 8

8.0 DISCUSSION OF RESULTS AND CONCLUDING REMARKS

1. The dynamometer provides adequate load absorption and speed control stability characteristics throughout the engine operating conditions tested, with capabilities to 500 BHP @ 1200 rpm to meet future load absorption requirements [Table 2].

2. The D.C. electric motor provides adequate motoring torque to start and accelerate the engine from rest (0 rpm) to the present maximum operational speed (1100 rpm) and future design speed (1200 rpm) without exceeding the continuous duty power rating of the D.C. motor (115%, 172.5 BHP, 701 N•m) [Table 1 and Fig. 12].

3. Cylinder pressure traces [Fig. 13, Fig. 14, and Fig.15] acquired as defined in Steps 3 and 8 of Section 6.2.2. of the Test Procedures demonstrate the difference in cylinder pressure under motored and fired conditions and the ability of the system to meet design criteria.

4. Adequate reserve potential of the D.C. motor and S.C.R. controller will allow for significantly increased loading to meet future requirements (i.e., 150% over-rating for one minute; 225 BHP, 915 N•m).

5. No significant torsional or other vibrational problems were experienced with the system.

6. The engine/dynamometer coupling operation is satisfactory, however further testing is required to determine long term durability.

The motoring dynamometer system, as delivered and installed, successfully met or exceeded all operational criteria as specified in the system requirements.

APPENDIX A

Upgrade Component Specifications and Cost

UPGRADE COMPONENT SPECIFICATIONS AND COST

Note: All prices are quoted in U.S. currency

1. Dynamometer.....$17,900.00

   - Mid-West Model 1519-W
   - 0 to 1200 rpm, 0 to 500 B.H.P. (approx. linear)
   - 1200 to 4000 rpm, 500 B.H.P. absorption capacity
   - 90 volt
   - Induction type
   - Wet gap
   - Eddy-current type

2. Coupling (Flexible).....$10,000.00

   - Holset "CB" Size 5
   - Torque ratings:
     Continuous = 5220 N•m (3850 lb•ft)
     Peak = 15,660 N•m (11,550 lb•ft)
   - 2400 rpm maximum speed

3. Load Cell.....$1,400.00

   - Lebow Model 3169
   - 10 kN (2000 lb) nominal load limit

4. Torquemeter.....$7,400.00

   - MCRT 6-02 T-10-3
   - Range: 0 to 1130 N•m (0 to 833 lb•ft)
   - Speed: 0 to 7500 rpm
   - Himmelstein 66300-R-B-N•m-RPM Readout Display
   - Overload rating = 2 times full scale reading

5. Clutch Coupling.....$1,860.00

   - Warner SFC-1525 H.T.
   - Eddy-current disconnect
   - 610 N•m (450 lb•ft) minimum capacity

6. Dynamometer Drive.....$27,150.00

   a. DC Electric Motor (direct current)

      - General Electric 150 HP motor
      - 1750 rpm
      - 500 volt armature
      - Shunt wound

b. Static Power Supply

- JEC Model 35150
- Input: 460 volt, 3-phase, 60 cycle
- Output: 0 to 500 volt DC
- Field: 300 volt DC

7. Dynamometer Controller.....$6,450.00

- Digalog Model 1022 A-STD
- RPM control: ± 1 rpm from 100 to 10,000 rpm
- Response: 700 rpm/sec
- Load control: 0.1%

8. Additional hardware and services $20,350.00

-Adapter coupling, shafting, mounting hardware
(custom fabricated/commercially available components)
-Component balancing
-Precision milling, fitting and alignment services

Total cost: $92,510.00

APPENDIX B

Upgrade Component Literature

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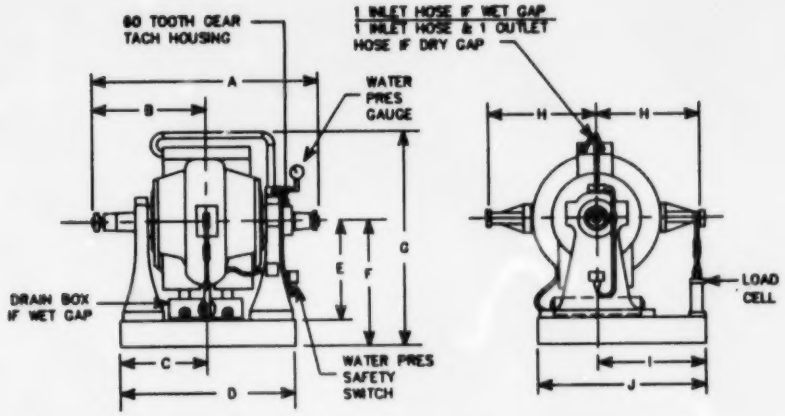
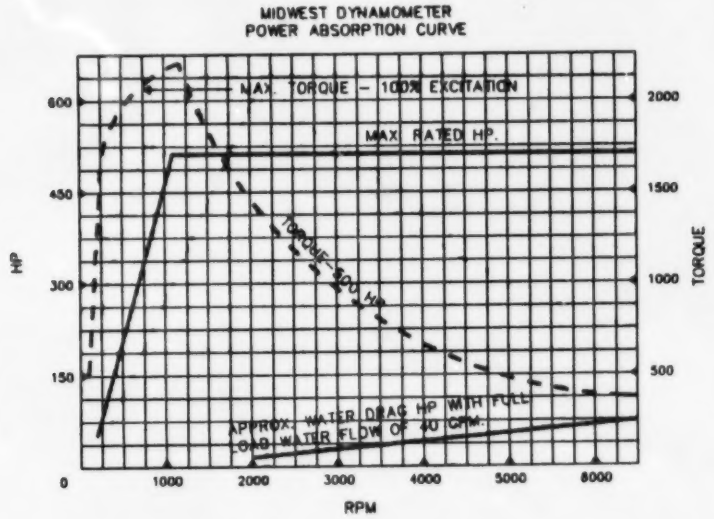
MODEL 1519WHS



DIMENSIONS IN INCHES									
A	B	C	D	E	F	G	H	I	J
51	25 1/2	20 1/4	40 1/2	22	28	47	21.008	24 3/4	38 1/2



HP	RPM	INERTIA LBS-FT²	MODEL
500	1200/8500	111	1519WHS

Figure D1. "Midwest Dynamometer Model 1519W" Specifications

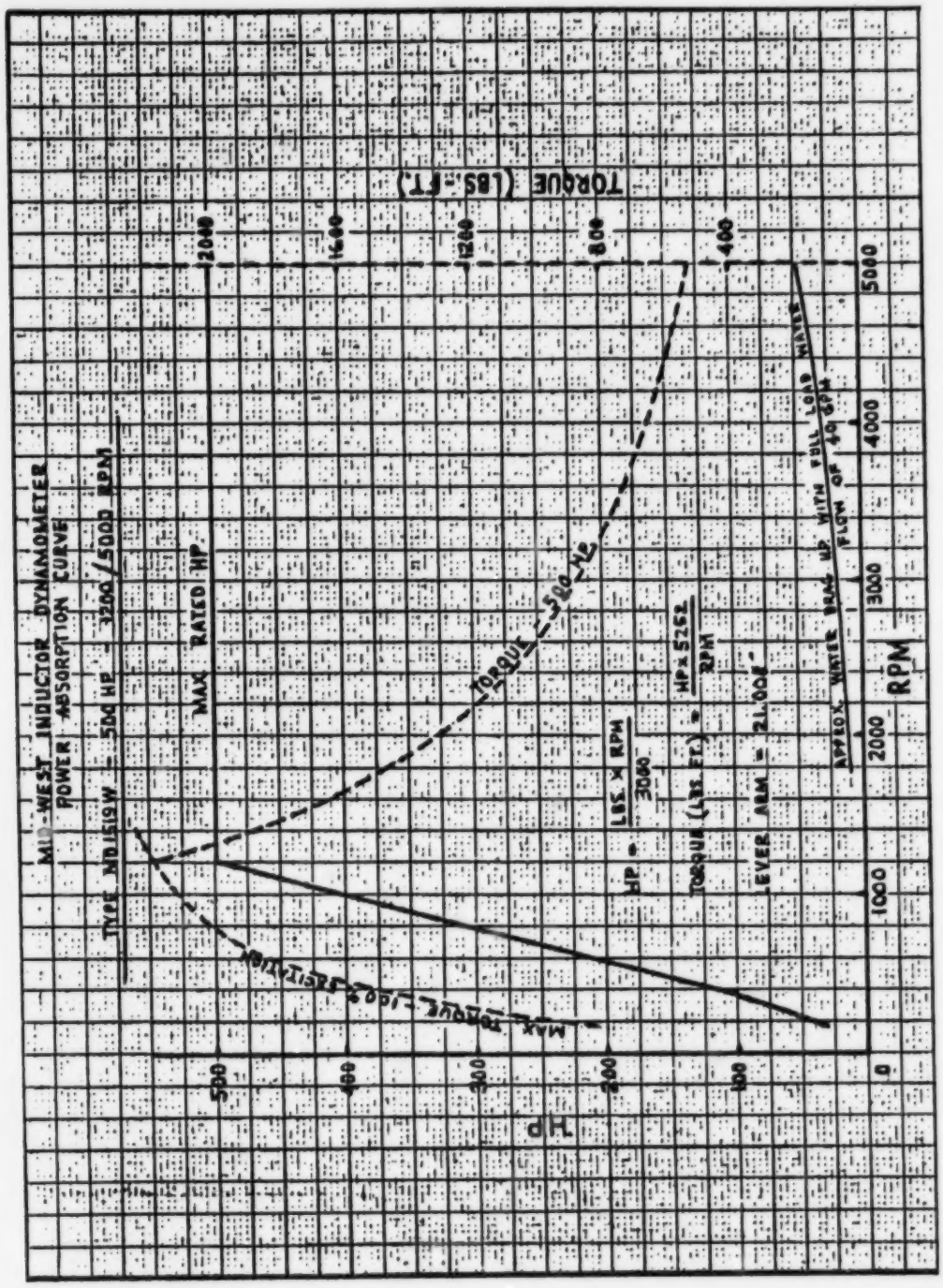


Figure D2. "Midwest Model 1519W" Power Absorption Curve

Holset "CB" Couplings

FOR ENGINE DRIVES

Engineering Data
SHEET 3564

Koppers Company, Inc.
Power Transmission Department
Baltimore, Maryland 21203

Application

Holset CB couplings can transmit the torque of all diesel engines currently marketed: as low as 100 HP at 2100 RPM; as high as 12000 HP at 450 RPM. Even larger sizes are within Koppers manufacturing facility capacities.

Holset CB (Cylindrical Block) couplings are employed when low torsional stiffness, combined with rugged reliability, are desired. These couplings also provide torsional vibration damping and can accommodate appreciable misalignment: offset, angular and axial.

Design

The design principle is solid rubber blocks loaded in compression. The molded blocks are housed in cavities formed between the blades of an outer sleeve, an inner hub and two end closures — the end ring and flywheel adapter plate. Rubber blocks are manufactured from natural rubber, when contamination is not a problem. For oil environments special synthetic rubber compounds are employed.

The sleeve and hub are manufactured from high strength and high ductility iron castings, conservatively stressed. End ring plates and flywheel adapter plates are made from ASTM A36 plate, or equivalent.

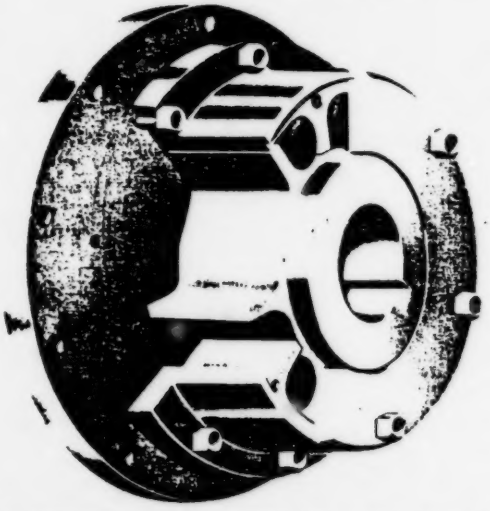
The Holset coupling provides an inherently fail-safe design. If premature rubber block failure occurs (due to incorrect selection or unforeseen overloads) the coupling continues to transmit torque, due to the intermeshing of sleeve and hub blades.

Torsional stiffness and damping properties are varied by selecting rubber blocks of the appropriate shore hardness. Block hardnesses of 40, 50, 60, 70, and 80 durometer can be employed. 50, 60, and 70 durometer are the preferred hardnesses.

The coupling sizes shown are indicative of what can be provided. Many special designs are supplied to meet the specific requirements of an application, such as: special low torsional stiffness, envelope restrictions, etc.

Rubber Block Life

Rubber block life is a function of the severity of the application. With correct selection and valid application load estimates, life will be approximately 2 to 10 years. Rubber blocks should be examined periodically to ensure that they are in serviceable condition.



Flywheel Mounting Arrangements (For shaft-to-shaft mounting see Brochure No. 1326-M 126 Rev 1)

The majority of installation requirements can be met by one of the following configurations:

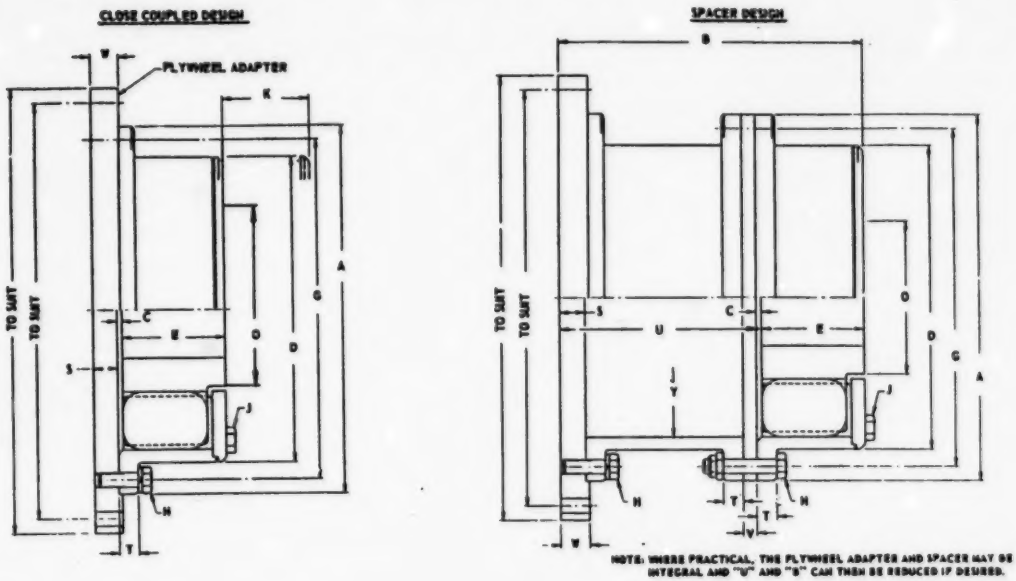
1. Close-coupled: coupling sleeve bolted to flywheel adapter plate, which is itself bolted and rabbeted to the engine flywheel. The coupling hub is mounted directly onto the driven-machine shaft. If the installation is such that there is insufficient space (K dimension) to permit rubber block replacement, then the 'Spacer' design can be employed.
2. Spacer: This design is employed when it is desired to provide space so that the engine or driven machine can be worked on or to change rubber blocks. This configuration comprises a flywheel adapter plate rabbeted and bolted to the engine flywheel and a spacer between the flywheel adapter plate and coupling sleeve. One flange of the spacer is rabbeted and bolted to the flywheel adapter plate. Sandwiched between the other spacer flange and the coupling sleeve flange is a solid plate which forms an end closure for the rubber blocks. After removal of the solid plate, the spacer can be dismounted, thus leaving a space between the engine flywheel and driven machine shaft.
3. Vertical Removal Concept: This design permits the vertical removal of the complete coupling, without disturbance of engine or driven machine. This is usually desirable on marine propulsion applications so that the complete coupling assembly can be lowered into position, after the engine and gearbox have been aligned and bolted down. This arrangement comprises a flywheel adapter plate rabbeted and bolted to the flywheel and to which the coupling sleeve is bolted. A flanged stub shaft is shrunk and keyed into the coupling hub. Sandwiched between the stub shaft flange and gearbox shaft flange is a split ring. After removal of the split ring, the complete coupling assembly can be lifted out vertically.

See page 2 for illustration of these mounting arrangements.

For Selection procedure refer to back page.

KOPPERS

Figure D3. "Holset CB" Coupling Engineering Data


CLOSE COUPLED DESIGN
FLYWHEEL ADAPTER
SPACER DESIGN
TO SUIT
TO SUIT
NOTE: WHERE PRACTICAL, THE FLYWHEEL ADAPTER AND SPACER MAY BE INTEGRAL AND "U" AND "S" CAN THEN BE REDUCED IF DESIRED.

CPLG SIZE	TORQUE RATINGS (1000's OF LB. IN.) NORMAL CONTINUOUS	MOMENTARY PEAK	VIBRATORY[1]	MAX. SPEED (R.P.M.)	MAX BORE (IN.)	WEIGHTS[2] (LB.) HUB (NO BORE)	RESILENT BLOCKS	SLEEVE & END RING	WR²[2] (1000's OF LB. IN.²) HUB	RESILENT BLOCKS	SLEEVE & END RING	DIMENSION (IN.) A[2]	B[2] MIN
1½	1.47	4.41	±.55	7200	1¾	3.9	.47	5.7	.005	.002	.034	6⅜	5 3/32
2	2.52	7.56	.95	5940	2⅛	6.5	.84	12	.014	.004	.102	7¾	6 3/32
2½	4.62	13.86	1.73	4840	2⅝	11	1.7	14	.037	.014	.197	9½	7
3	8.4	25.2	3.15	4130	3 3/16	20	3	23	.084	.037	.450	11⅛	7⅞
3½	14.7	44.1	5.51	3470	3 13/16	34	5	37	.251	.089	.999	13¼	9 1/16
4	25.2	75.6	9.45	2920	4⅛	59	9	62	.511	.222	2.379	15¾	9⅞
5	48.2	138.6	17.33	2400	5⅛	107	15	109	1.426	.592	6.281	19⅛	12⅛
6	84	252	31.5	1950	6⅛	191	28	203	3.795	1.627	17.64	23½	14⅛
7	126	378	47.25	1760	7 1/16	285	42	274	7.464	3.084	30.39	26⅛	15 1/16
8	168	504	63.0	1600	8⅛	378	58	353	12.35	5.109	47.31	29	17 1/16
9	252	756	94.5	1400	9⅛	562	83	531	23.48	9.82	95.76	33	20¼
10	336	1008	123.5	1265	10⅛	761	113	702	37.64	15.99	150.2	36¼	22
12	462	1386	173.3	1150	12⅛	1038	154	963	63.45	26.96	240.1	40	25⅛
13	630	1890	236.3	1110	13½	1524	200	1064	106.9	39.57	297.3	41½	27½
14	840	2520	315.0	1030	14⅛	2000	234	1361	167.9	55.06	458.5	44½	29 1/16
16	1260	3780	472.5	960	16⅛	3063	258	1392	336.1	75.48	545.8	48	33⅛
18	1574	4722	590.0	900	21	4105	266	1800	622.9	96.51	833.4	51⅛	33⅛
20	1937	5810	726.2	810	24	5248	297	2135	997.0	132.3	1,192	56⅛	35

NOTES: 1. Vibratory torque values tabulated relate to vibration frequencies up to 500 vib/min. For higher frequencies coupling vibratory torque capacity is derated on the following basis:

$$T_v = T\sqrt{\frac{500}{F}}$$

where T_v = Vibratory torque capacity (lb.in.) at frequency F (vib/min.).
T = Vibratory torque (lb.in.) from table.
F = Frequency (vib/min.) at which vibratory torque capacity is required.

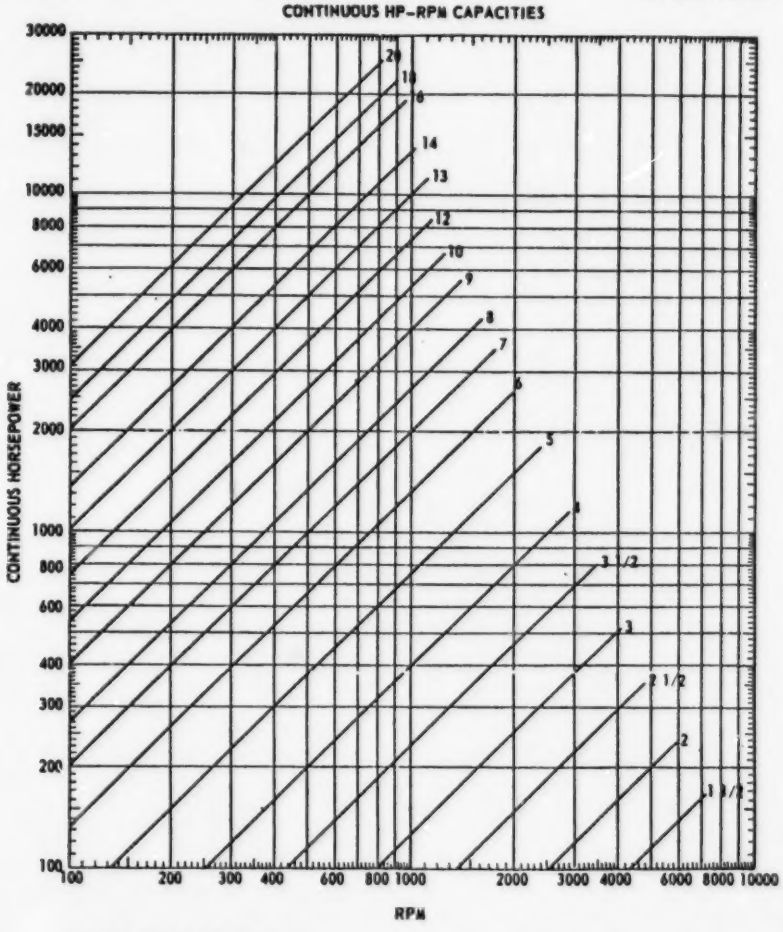
Figure D4. "Holset CB" Engineering and Dimensional Specifications

Selection

The following procedure should be followed when selecting a Holset CB type Coupling:

1. Select a coupling that has a continuous rating greater than the application rating. Use the 'Continuous HP - RPM' curves below or the 'Normal Continuous Torque' table on page 2 for this purpose.
2. Check that the coupling 'Momentary Peak Torque' capacity, from the table on page 2, is adequate for the peak and shock torques of the drive system.
3. Check that the coupling 'Vibratory Torque' capacity, from the table on page 2, is adequate for the vibratory torque conditions of the drive system.
4. Select the mounting arrangement (close coupled, spacer or vertical removal) desired from the illustrations on page 2 and the description on the front page.
5. Check that the mounting details provided in page 2 (maximum bore, flange diameters, lengths, etc.) are suitable or can be modified to suit the connected equipment requirements.

Note: Floating shaft arrangements, tandem couplings (for reduced torsional stiffness), combined clutch-coupling designs, etc. are manufactured to order.



Coupling Damping Capacity

Coupling specific damping torque can be estimated from the following equation:

$$C = \frac{K}{M\omega}$$

Where, C = Coupling specific damping torque, Lb.in.sec./rad.

K = Coupling torsional stiffness (refer to Koppers), Lb.in./rad.

ω = Vibration frequency, rad./sec.

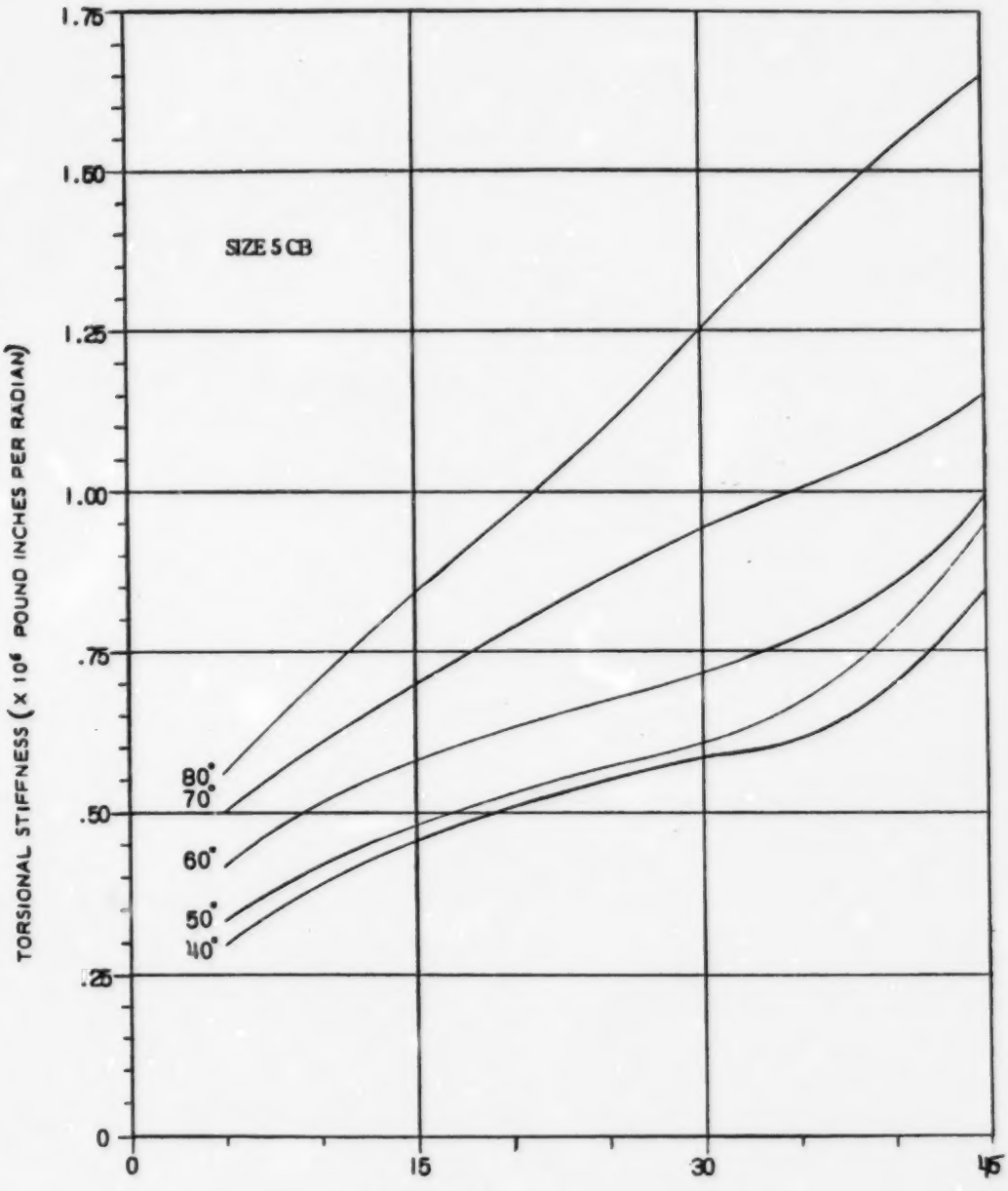
M = Coupling Dynamic Magnifier, non dimensional

= 12, for 50 durometer resilient blocks

= 9, for 60 durometer resilient blocks

= 7, for 70 durometer resilient blocks

Figure D5. "Holset CB" Coupling - Contiuous HP-RPM Rating Curve



TORSIONAL STIFFNESS VALUES FOR HOLSET RESILIENT COUPLINGS*

(* Manufactured Under U.S. Patent Nos. 2621493, 2719412, 2764003, 2873590)

STIFFNESS VALUES SHOWN APPLY TO SIZE 5 TYPE CB HOLSET COUPLINGS LISTED IN BULLETIN NO. 230
HIGHER OR LOWER VALUES CAN BE PROVIDED BY MEANS OF SPECIAL DESIGNS.

Figure D6. "Holset CB" Coupling - Torsional Stiffness Values

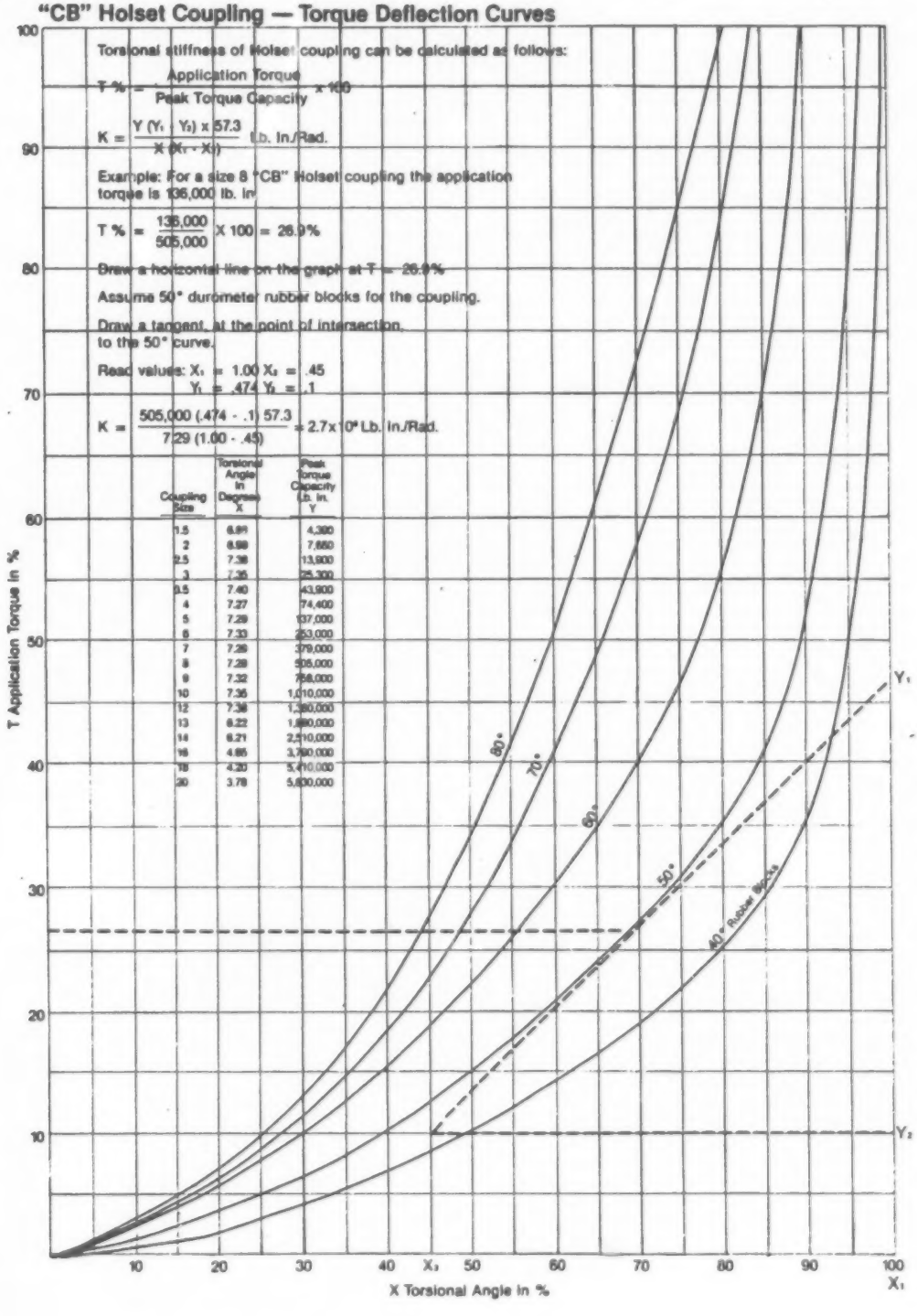
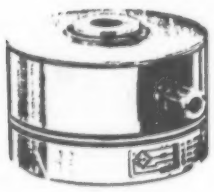

"CB" Holset Coupling — Torque Deflection Curves
Torsional stiffness of Holset coupling can be calculated as follows:
T % = Application Torque / Peak Torque Capacity x 100
K = Y (Y1 - Y2) x 57.3 / X (X1 - X2) lb. in./Rad.
Example: For a size 8 "CB" Holset coupling the application torque is 136,000 lb. in
T % = 136,000 / 505,000 X 100 = 26.9%
Draw a horizontal line on the graph at T = 26.9%
Assume 50° durometer rubber blocks for the coupling.
Draw a tangent at the point of intersection to the 50° curve.
Read values: X1 = 1.00 X2 = .45
Y1 = .474 Y2 = .1
K = 505,000 (.474 - .1) 57.3 / 729 (1.00 - .45) = 2.7x10⁶ Lb. in./Rad.
Coupling Size | Torsional Angle in Degrees X | Peak Torque Capacity Lb. In. Y
1.5 6.91 4,380
2 6.59 7,660
2.5 7.38 13,900
3 7.35 25,300
3.5 7.40 43,900
4 7.27 74,400
5 7.29 137,000
6 7.33 253,000
7 7.28 379,000
8 7.28 505,000
9 7.32 758,000
10 7.35 1,010,000
12 7.38 1,380,000
13 8.22 1,880,000
14 6.21 2,510,000
16 4.85 3,760,000
18 4.20 5,410,000
20 3.78 5,830,000
T Application Torque in %
X Torsional Angle in %
80°
70°
60°
50°
40° Rubber Blocks
Y1
Y2
X2
X1

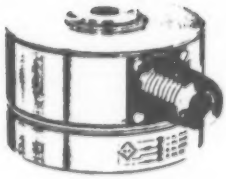
Figure D7. "Holset CB" Coupling - Torque Deflection Curves

GENERAL PURPOSE LOAD CELLS-STAINLESS STEEL

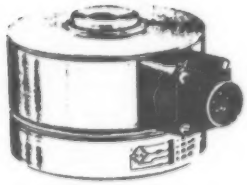
TENSION AND COMPRESSION 500 LBS. TO 3000 LBS.



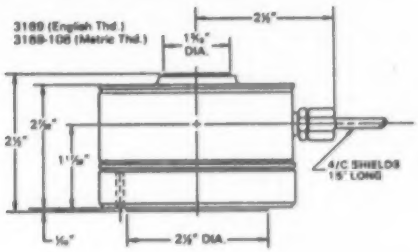
3169 (ENGLISH THD.)
3169-106 (METRIC THD.)

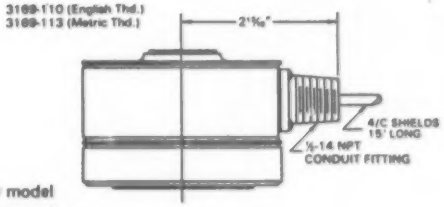


3169-110 (ENGLISH THD.)
3169-113 (METRIC THD.)

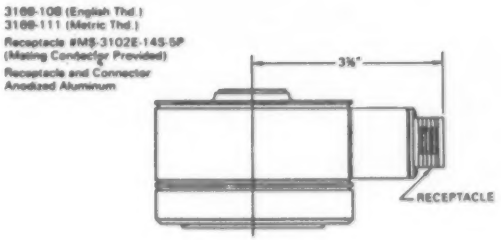


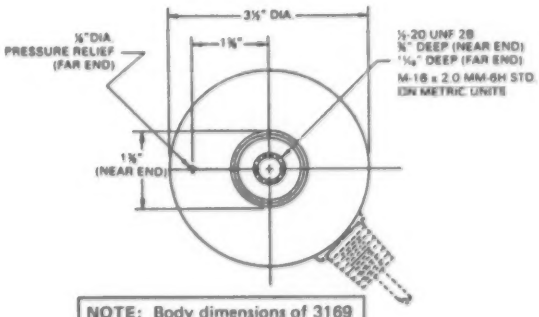
3169-108 (ENGLISH THD.—MS RECEP.)
3169-111 (METRIC THD.—MS RECEP.)





To order, specify model number and load capacity - see chart opposite page.




3½" DIA.
⅛" DIA. PRESSURE RELIEF (FAR END)
1⅜"
½-20 UNF 2B ⅜" DEEP (NEAR END) 1 1/16" DEEP (FAR END)
M-16 x 2.0 MM-6H STD. ON METRIC UNITS
1⅜" (NEAR END)

NOTE: Body dimensions of 3169 identical on all models.

REQUEST CERTIFIED DRAWINGS BEFORE DESIGNING MOUNTINGS OR FIXTURES. DIMENSIONS AND SPECIFICATIONS ARE SUBJECT TO CHANGE WITHOUT NOTICE.

Figure D8. "Lebow Model 3169" Load Cell Dimensional Specifications

FEATURES

- stainless steel
- hermetically sealed
- barometrically compensated
- low deflection
- proven design and performance
- tension and compression
- low sensitivity to extraneous loads

The 3169 Stainless Steel Load Cell offers sealed, barometrically compensated construction. It is ideally suited for scales and other critical weighing applications. This compact load cell's temperature compensation circuit is located in close proximity to the strain gage bridge which provides more effective compensation where the internal and external load cell temperature can vary. Precision performance as well as the structural integrity required to withstand extraneous loads are also features of this rugged load cell.

NOMINAL LOAD LIMIT CAPACITY F_z		STATIC OVERLOAD CAPACITY % OF NOMINAL CAPACITY	STATIC EXTRANEOUS LOAD LIMITS			DEFLECTION AT NOMINAL LOAD LIMIT INCHES	RINGING FREQUENCY Hz
LBS.	NEWTONS		SHEAR F_x or F_y LBS.	BENDING M_x or M_y LB. INCHES	TORQUE M_z LB. INCHES		
500	2K	150	2619	4583	2895	.003	1950
750	3K	150	2619	4583	2895	.003	2225
1K	5K	150	2619	4583	2895	.003	2440
2K	10K	150	2619	4583	2895	.003	3900
2.5K	12.5K	150	2619	4583	2895	.003	4600
3K	15K	150	2619	4583	2895	.003	5000

Static extraneous load limits are calculated such that only one extraneous load (F_x or F_y or M_x or M_z) can be applied simultaneously with half the nominal load limit capacity. Also note that these values are for static application. Ringing frequency values are calculated or determined by test with no external force or load.

F_z - Force on load axis.
$F_{x,y}$ - Side loads (shear forces).
$M_{x,y,z}$ - Bending moments.

NOTE: Refer to pages 48 and 49 for Extraneous Load Coefficients

SPECIFICATIONS	MODEL NO. 3169
Output at rated capacity: millivolts per volt	2 nominal
Nonlinearity: of rated output[1]	± 0.05%
Hysteresis: of rated output[2]	± 0.05%
Repeatability: of rated output	± 0.02%
Zero balance: of rated output	± 5.0%
Creep: in 20 minutes of rated output	<± 0.02%
Bridge resistance: ohms nominal	350
Temperature range, compensated: °F	+ 70 to + 170
Temperature range, useable: °F	- 65 to + 200
Temperature effect on output: of reading per °F	± 0.002%
Temperature effect on zero: of rated output per °F	± 0.002%
Excitation voltage, maximum: volts DC or AC rms	20
Insulation resistance, bridge/case: megohms at 50 VDC	>5000
Number of bridges	1

[1] ± 0.03% available [2] ± 0.02% available

Figure D9. "Lebow Model 3169" Load Cell Engineering Specifications

TECHNICAL SPECIFICATION

BULLETIN 766

MCRT®6-02T Non-Contact Torquemeter

MAX. TORQUE–15,000 lb.-in.
SPEED – 0 - 7,500 rpm

GENERAL DESCRIPTION

The MCRT®6-02T is a compact, high accuracy, flanged torquemeter well adapted for vehicle drive-line measurements and continuous monitoring and feedback applications. It uses a rotating strain gage torque bridge, temperature compensated for drift and modulus. The bridge is connected to a stationary electronic readout via integral, non-contact rotary transformers.

The torquemeter is immune to water, lubricants, coolants, vibration, etc. The elimination of slip-rings permits high accuracy low level measurements with long, maintenance-free life. Thrust and bending loads are inherently cancelled by the transducer design. An optional, integral non-contact speed pickup may be specified when ordering.

Linearity: 0.1%

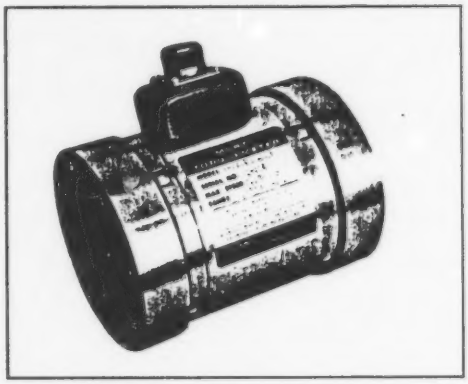
Temperature Effects: From 75 to 175° F maximum drift is 0.2% of full scale and maximum error due to modulus change is 0.2% of reading.

Maximum Operating Temperature: 220° F, assuming permanent lubrication. Above 175° F, the maximum shaft speed may have to be de-rated.

Readout: Any carrier amplifier suitable for strain gage service may be used.

Excitation Voltage: 10 volts rms, maximum.

Nominal Output: 0.75 millivolts/volt (open circuit).



Standard Ratings:

MODEL	FULL SCALE TORQUE	TORSIONAL STIFFNESS	MAXIMUM BENDING MOMENT	MAXIMUM ROTATING INERTIA	MAXIMUM WEIGHT
MCRT®6-02T	(lb. – in.)	(lb. – in./rad.)	(lb. – in.)	(in. – oz. sec.^{2})	(lbs.)
–(1-3)	1,000	602,000	500	0.60	13.8
–(2-3)	2,000	1,375,000	1,000	0.60	13.8
–(4-3)	4,000	2,640,000	2,000	0.60	13.8
–(6-3)	6,000	2,430,000	3,000	0.90	17.0
–(10-3)	10,000	2,930,000	5,000	0.90	17.0
–(15-3)	15,000	3,530,000	5,500	0.90	17.0

Overload Capacity: 2 times full scale rating.

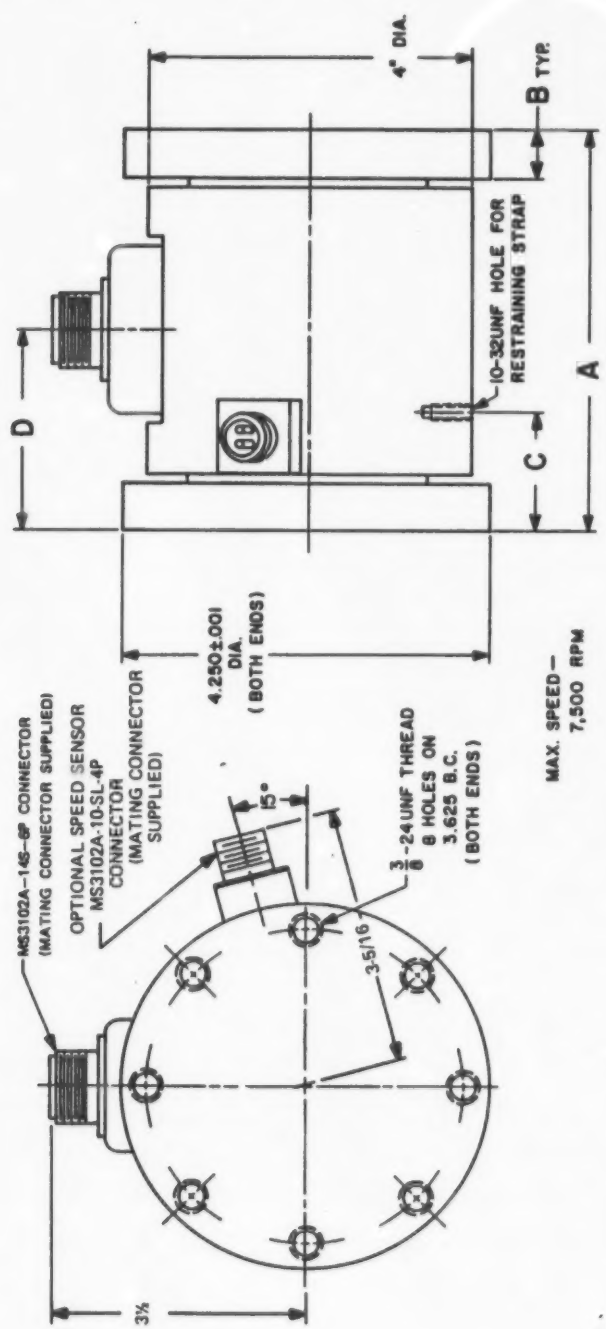
Shaft Speed: 0 to 7,500 rpm, bi-directional. Optional speed pickup produces 60 pulses per shaft revolution.

Construction:

NOTES:
(1) Maximum speed rating assumes permanent lubrication. Consult factory for higher speed operation.
(2) When combined axial and bending loads are present, the bending capacity must be de-rated. Consult factory.
(3) Stator should be compliantly restrained from rotating.

S. HIMMELSTEIN AND COMPANY
2490 PEMBROKE AVENUE / HOFFMAN ESTATES, IL 60195 / 312/843-3300

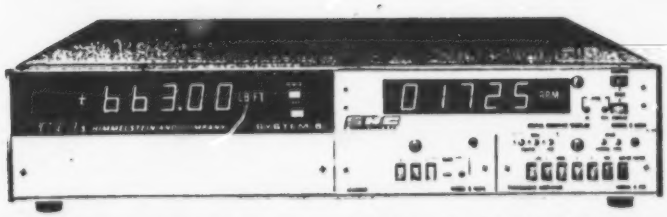
Figure D10. "Himmelstein MCRT 6-02T" Technical Specifications



RANGE	A	B	C	D	MAX. WEIGHT
BELOW 6,000 lb in.	4 11/16	9/16	1 3/8	2 11/32	13.8 LB
6,000 lb in. & ABOVE	5 7/16	15/16	1 3/4	2 23/32	17 LB

Figure D11. "Himmelstein MCRT 6-02T" Dimensional Specifications

SPARE PART NUMBER	QTY PER SYSTEM	BRIEF DESCRIPTION
* MCRT 6-02T(1-4)	1	NON-CONTACT TORQUEMETER
6-201	1	TRANSDUCER AMP, A-C
6-402	1	2 CHANNEL SCANNER
6-562A	1	DIGITAL COUNTER/DISPLAY
6-138	1	A-D + CABINET W/POWER
* 224-3642-50	1	TRANSDUCER CABLE
* 224-3683-50	1	SPEED CABLE



Torque and Speed Readout

Order No. 66300

Inputs: One strain gage torquemeter, load cell or pressure sensor **and** one frequency producing sensor.

Outputs: ±5 volt analog of each input. BCD (option).

Displays: Dual 5 digit displays with engineering unit scaling.

Illuminated legends: Two, customer selected.

This instrument will simultaneously display **torque** and **speed**, or **head** and **flow**, or **force** and **velocity** when equipped with appropriate sensors. An optional BCD output is available. The Model 66300's strain gage channel is functionally identical to the Model 66200. It also contains independent signal conditioning for and display of a frequency producing sensor. The frequency conditioner is a true digital counter, has high sensitivity, a wide range crystal controlled adjustable gate period, an auxilliary F-to-V converter, conditioner and display test functions, remote display hold and many other valuable features.

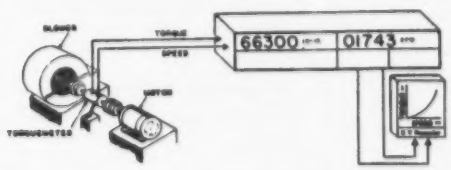
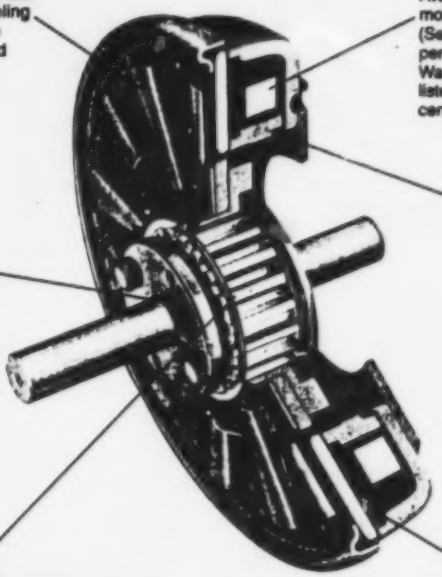


Figure D12. "Himmelstein" Components List and Readout Description

Selection and Features

Custom Design Clutches & Brakes

Versatility and Flexibility



Armature
Fluted and segmented. Designed as a cooling device to dissipate maximum heat and increase life.

Coil
Available in various voltages for each model. Warner Electric controls (Section C) provide optimum performance and controllability. All Warner Electric units are either UL listed or recognized. All are CSA certified.

Bushings
Standard industry bushings are used in all the larger sizes to meet your shaft size requirement. Several bore sizes are available as standard in each of the smaller models.

Magnet or Field
Brake magnet mounts to any machine member. Warner Electric clutches are available in flange mount or bearing mount designs.

Armature Drives
Heavy duty spline drive absorbs shock. Rugged, long life materials used in outer and inner spline members. Pin drive design available for normal, lighter duty applications. Anit-backlash armatures available for sizes 170, 250 and 400.

Friction material
Standard friction material represents the optimum in high torque performance and long life. Long wearing LK facing is available in the larger models to meet application requirements where exceedingly long life is a critical design factor.

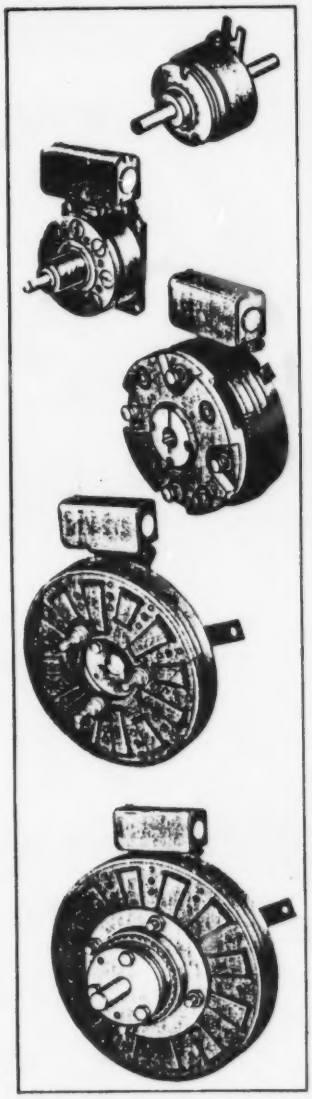
Custom design with off-the-shelf components.
For maximum mounting versatility and design flexibility Custom Design products may be designed into the most demanding and space restrictive applications. They require additional engineering and assembly capability, but their lower initial cost and wider range of sizes makes them an ideal consideration for many applications. Like all Warner Electric packaged clutches and brakes, they never need adjustment, and they are built to the same standards of quality and performance.

Wide range of sizes
Assembled around the basic components of an electric clutch-brake, magnet and armature. Custom Design products come in a tremendous range of sizes, torque ratings and configurations.

Figure D13. "Warner" Electric Clutch Design Features

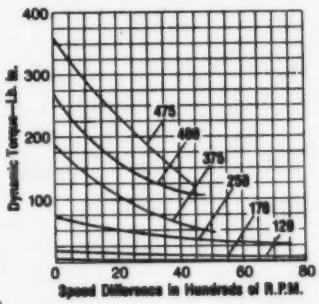
Selection and Features

Custom Design Clutches & Brakes

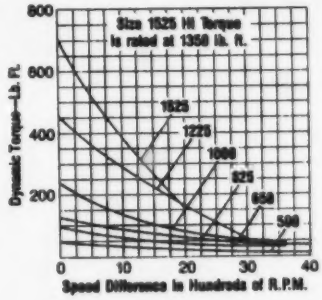


Product Features
Custom design brakes and clutches are user assembled from standard components for optimum performance in the smallest possible package size.

- Easily adaptable to any mounting requirement
- Low initial cost
- Wide range of models and options
- 10 sizes from 1 1/4" to 15 1/4" diameter
- 45 models of clutches, brakes and motor brakes
- Torque range: 5 lb. in. to 1350 lb. ft.
- Horsepower capability to 100 HP



Easy-to-Select
Easy-to-use selection charts make choosing the right model as simple as reading the motor nameplate and determining the speed at the clutch or brake location.



How to Order
Specify size, voltage and bore size. See parts list pages for each model for details.

Selection Guide
A complete listing of all models can be found on pages B-10 & B-11.

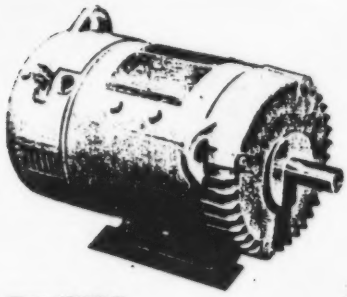
Model Size	Max. Rated Torque	Envelope Size Diameter in.	Envelope Size Length in.
120	5 lb. in.	1 1/4	1 3/8
170	15 lb. in.	1 3/4	1 7/8
250	70 lb. in.	2 5/8	3 1/2
400	270 lb. in.	4 1/4	2 3/4
500	50 lb. ft.	5 1/4	4
650	95 lb. ft.	6 3/4	3 5/8
825	150 lb. ft.	8 5/8	4 5/8
1000	240 lb. ft.	10 3/8	5 7/8
1225	465 lb. ft.	12 3/4	6 3/8
1525	700 lb. ft.	15 3/4	6 1/2
1525 Hi Torque	1350 lb. ft.	15 3/4	6 1/2

Figure D14. "Warner" Electric Clutch Engineering Specifications

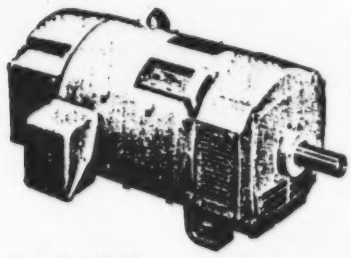
INSTRUCTIONS GEH-3967I

DIRECT CURRENT MOTORS AND GENERATORS

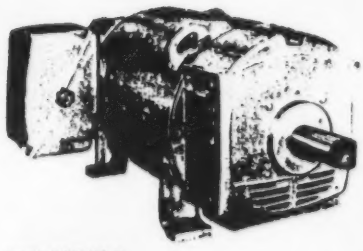
TYPE CD FRAMES 180AT-500AT



(Photo MG5339-2)



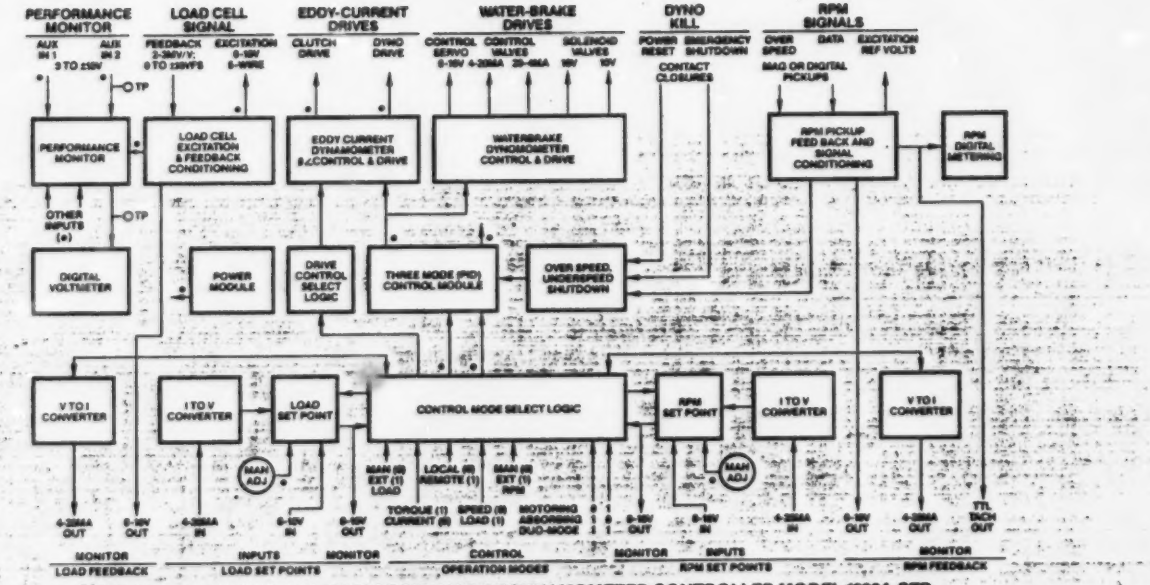
(Photo MG-5423-3A)



(Photo MG5423-4)

GENERAL ELECTRIC

Figure D15. "General Electric" Direct Current Motor Detail



BLOCK DIAGRAM AND INTERFACE SIGNALS OF DYNAMOMETER CONTROLLER MODEL 1022A-STD

ORDERING INFORMATION

Standard Models.
Each includes Operator's Manual, mating connectors and rack mount adapters.

Model 1022A-STD.
Eddy-current and water-brake controller

Model 1022A-STD-WB.
Water-brake controller only

Optional Features and Accessories.

SA Servo Amplifier, separate external enclosure for water-brake dynamometers with servo type valves (±24V @ ±10A)

TC Throttle Controller provides fast acting throttle or rack servo for total test control. Control modes include: RPM, Load, Power, Rack Position, Fuel Flow Rate, Manifold Vacuum. Drives solenoid, pneumatic, hydraulic or servo motor actuators.

TA Throttle Actuator accessories. Fast, rugged, all electric solenoid type, with 45° travel. Comes in 1.4 lb and 5.2 lb-ft work output models.

MC Motoring Control, has mode select switches, dead band adjust potentiometer, eddy-current clutch drive circuitry.

VI Dual voltage-to-current converter, provides 4–20 mA outputs for external monitoring of RPM and Load (feedback voltage outputs standard)

OM Additional Operator's Manual

CS Additional Connector Set

Consult factory for quantity and OEM discounts.
Delivery Stock to 60 days, FOB destination in U.S.A.
Specifications subject to change without notice.
Prices higher outside U.S.A.

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DIGALOG
P.O. Box 3315, Ventura, CA 93006-33
805/644-9928 • Telex: 756323

Figure D16. "Digalog" Dynamometer Logic Block Diagram

REPORT DOCUMENTATION PAGE/PAGE DE DOCUMENTATION DE RAPPORT

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4

TITLE, SUBTITLE/TITRE, SOUS-TITRE

5 NRC B-2400 Single Cylinder Research Engine Test Facility: Dynamometer System Upgrade

AUTHOR(S)/AUTEUR(S)

6 B. Moyes, H. Rook, M. O'Brien, G. Webster

SERIES/SÉRIE

7 Laboratory Memorandum

CORPORATE AUTHOR/PERFORMING ORGANIZATION/
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8 Division of Mechanical Engineering

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9 Transport Canada, Transportation Development Centre

DATE	FILE/DOSSIER	SPECIAL CODE/ CODE SPÉCIALE	PAGES FIGURES REFS.
10 1989/11	11	12	13a 49 ix 13b 15 13c

NOTES Single-cylinder research engine, medium speed diesel, motoring
14 dynamometer, test facility.

DESCRIPTORS(KEY WORDS)/MOTS-CLÉS

15

SUMMARY/SOMMAIRE
Defines the dynamometer system requirement, acquisition program objectives, equipment selection rationale, equipment installation/
16 commissioning and evaluation test/results.

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